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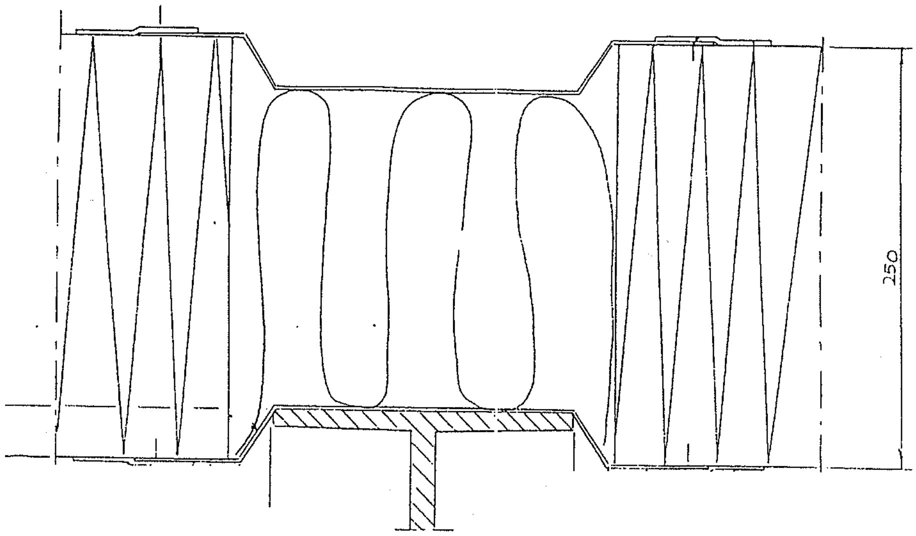
INVESTIGATION ON FLOATING LID CONSTRUCTION PIT WATER STORAGE OTTRUPGAARD, DENMARK

ALFRED HELLER



REPORT

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DEPARTMENT OF BUILDINGS AND ENERGY
TECHNIAL UNIVERSITY OF DENMARK

Preface

This report is part of a series of two reports, representing the conclusion of the research project, "Floating Lid Construction for Pit Water Storage - Phase I" (in Danish: "Lågkonstruktioner til damvarmelagre, Fase I"), journal no. 51181/95-0030, financed by "Energistyrelsen", Danish Energy Agency through the renewable energy development program, UVE. The other report of the series, "Floating Lid Constructions for Pit Water Storage - A Survey", gives a survey of the known floating lid constructions in Denmark, Sweden and Germany. Floating lid constructions seem not to be applied in other countries in Europe.

Participants:

Alfred Heller	(Leader of Project) Department of Buildings and Energy Technical University of Denmark
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Resume

At Ottrupgaard a pit water storage of 1,500 m^3 and a lid area of about 700 m^2 is built for seasonal storage of a solar collector field of 560 m^2. The lid price is the largest component of a pit water store with a cost share of about 57%, more precisely 1,163 Dkr./m^2. There are two major components which stand for about 80 percent of the expenses for CSHPSS; Solar collector (60%) and lid constructions (20%). Due to these facts the development of lid constructions is crucial for the development of pit water storage as it seems that the development of solar collectors will not have a breakthrough in the near future.

The Ottrupgaard lid design is basically a sandwich element construction of PUR-foam between two metallic covers. The elements are joint in situ by special steel profiles. A two-step sealing with silicone mass and bitumen-tape is applied to tighten the construction.

To ensure a proper lid design, two test lids of 1.5x1.5 metres are tested at the Department of Buildings and Energy under ambient conditions floating on hot water. The test lids were examined for tightness by a number of means. The results showed critical construction errors of the first lid design. A redesigned lid showed acceptable results, but also some water penetration into the lid insulation. The entered water gathers on the colder side of the construction where it does no harm. Anyway the worst case of hot water lying at the bottom of the insulation is examined by experiments. The experiments proof that the water will penetrate into the PUR-foam in time. It is not to say from the experiments if the PUR-foam cells are damaged due to this penetration. Anyway the heat resistance of the insulation material decreases with increased presence of water which leads to larger heat losses through the lid which is undesirable. More work has to be done on such subjects to understand the effects of hot water on insulation materials and thereby to ensure proper lid constructions.

In situ examinations of the lid show considerable heat losses through the lid borders. The concept can and must be improved to avoid such heat losses.

The overall experience is that the construction is much too expensive but can be optimized technically as well as economically. The process of handling, joining the sandwich elements and tightening the construction is much too demanding and should be changed. The concept as such is working well if these problems are solved.

To ensure proper lid design and monitoring, measurement methods of finding moisture and damp in highly insulated constructions plus conductive heat transport are to be found.

Although there is no applicable lid design after this first project phase, the project has brought the lid design a step ahead. The project has disclosed a finite number of ways to go on and find final solutions.

Contents

1. Introduction

The application of hot water storage to district heating systems makes exploitation of waste heat from e.g. electricity production and industries possible and enables the employment of solar heating. Storage is expensive and is therefore applied to special purposes only. Hence, development of low cost storage is required for the propagation of waste heat storage and solar heating systems.

Storage is categorized into short time and seasonal storage, dependent on the storage cycle - the time between two chargings. Although the current work is concentrating on seasonal storage, the results can be applied to other storage types.

In the current storage type water is applied as a storage medium due to the advantageous properties of the material. Water is mostly available, is cheap, is not poisonous and has good physical properties, like the ability of thermal stratification, high heat capacity and high heat transfer rate.

Water storage can be designed in many ways as cave-storage, steel-tank storage and so on. Steel tanks are rather expensive but a common known and accepted concept. Hence such tanks are dominating. On the other hand pit water storage is simple to build and cheap, but a rather unknown concept which is to be developed. In Denmark pit water storage is seen as the most promising candidate of seasonal hot water storage with high expected reliability and low installation cost.

Basically, there are two types of lid constructions which can be applied to pit water storage; bearing and floating lids. Bearing lids are part of the static construction of the pit, similar to the roof construction of a house. Such constructions are rather expensive and therefore alternatives are required. Floating lid constructions are basically designed to float on the pit water surface without any static structure. In some cases the lid is supported by a simple steel construction or a wire net for critical periods with no water in the pit.

Although floating lid constructions are noticeably cheaper than bearing lids, the construction accounts for over 50% of the total cost for a hot water pit which proves the necessity of developing more economical designs. In the past the lid designs have turned out to be a technically difficult construction. The most dominating difficulty lies in the fact that the lid insulation is to be kept dry. The first lid construction, tested at the Department of Buildings and Energy, was found unreliable [Duer, 1995b]. Experiences from this investigation will be summarized below. Based on these experiences a redesigned lid construction is tested and applied to the Ottrupgaard pit water storage.

The pit water storage concept is based on an artificial ditch, tightened by a hybrid clay layer liner at the pit and a floating lid at the top. The concept was, among others, presented at Workshops of the CSHPSS Working Group in 1994 by Sørensen, 1994 and Wesenberg, 1994. The clay layer construction was presented at the ISES Solar World Congress in 1993 by Duer and Svendsen and will not be treated in this work.

A pilot hot water pit is built in Ottrupgaard, Jutland, Denmark in 1993. The first results from this system are presented e.g. at a workshop in Stuttgart in 1995 by Wesenberg, 1995a and a final report is given by Wesenberg, 1995b.

The objective of the current project is to investigate the Ottrupgaard design, to give a status of floating lid construction designs and to sketch future design developments.

The objective of the present report is to describe the Ottrupgaard lid design in detail and to summarize the experience with the tested lid designs.

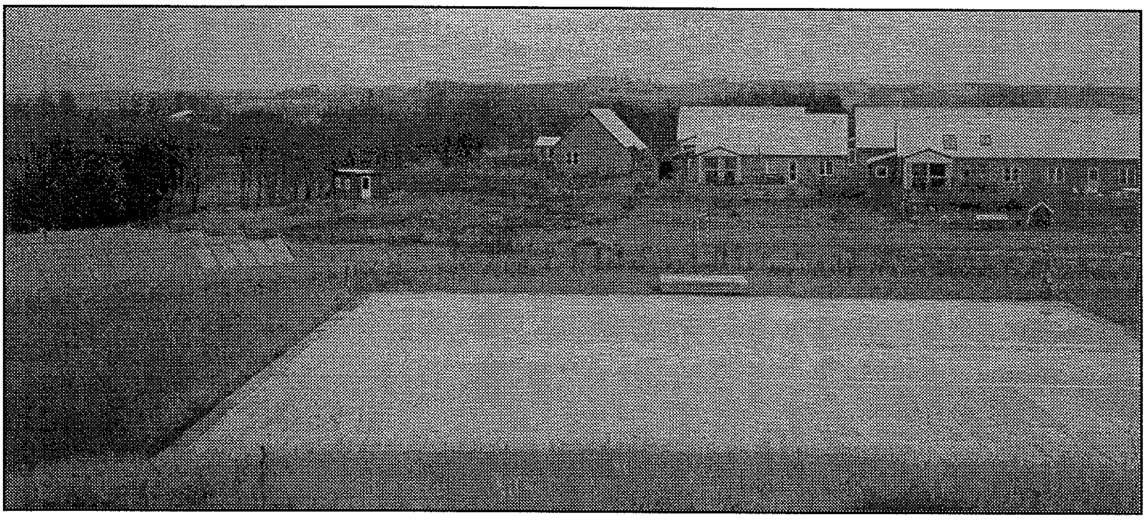


Figure 1 The Ottrupgaard Pit Water Storage.

2. The Ottrupgaard Lid Concept

Industrial products are often low-cost compared with other products. To ensure high quality and utilize the economical advantages of such a product, industrially produced sandwich elements of polyurethane foam (PUR-foam) are applied to the Ottrupgaard lid. Such elements are e.g. used for refrigerator vans and containers. The following figures give an idea of the composition of such sandwich elements.

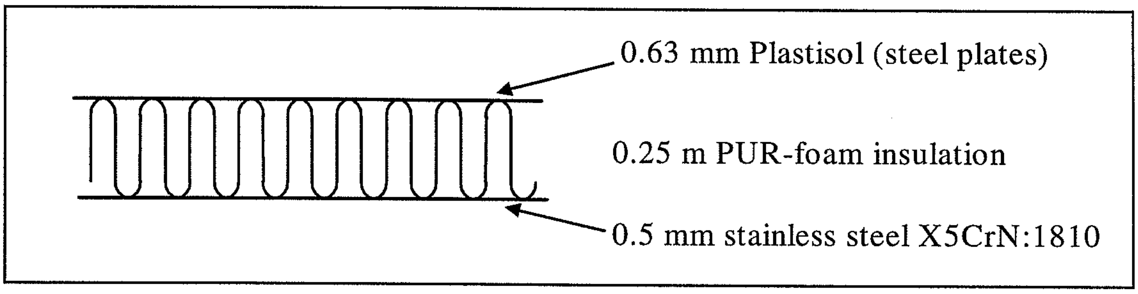


Figure 2 Sandwich element applied to the Ottrupgaard lid. The element is basically two plates filled with PUR-foam as insulating material. This composition is rather stiff and stable without any additional stabilizing constructions.

A picture taken from the top of the lid is given in Figure 3

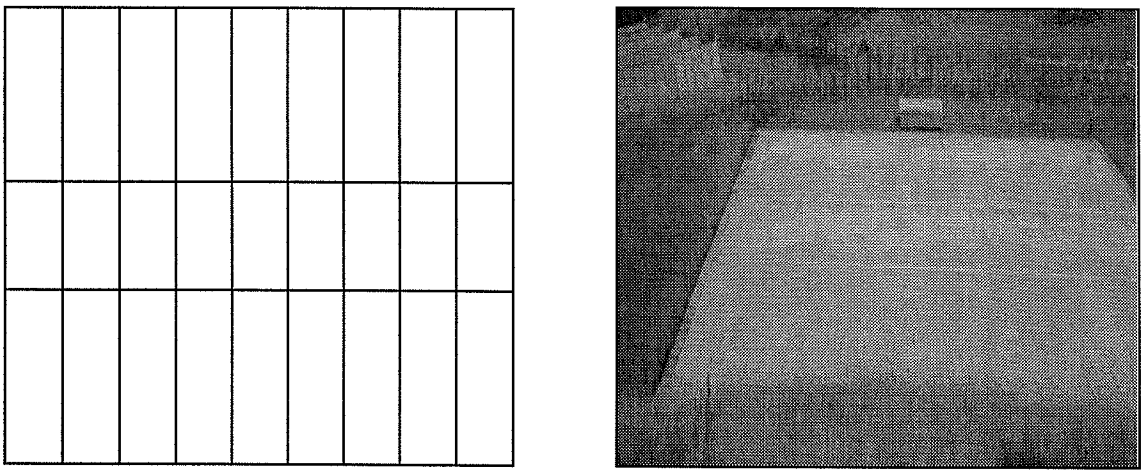


Figure 3 A sketch and a picture of the lid taken from the top. There are three rows with elements jointed as shown in Figure 4. The rows are connected by joints as shown in Figure 5.

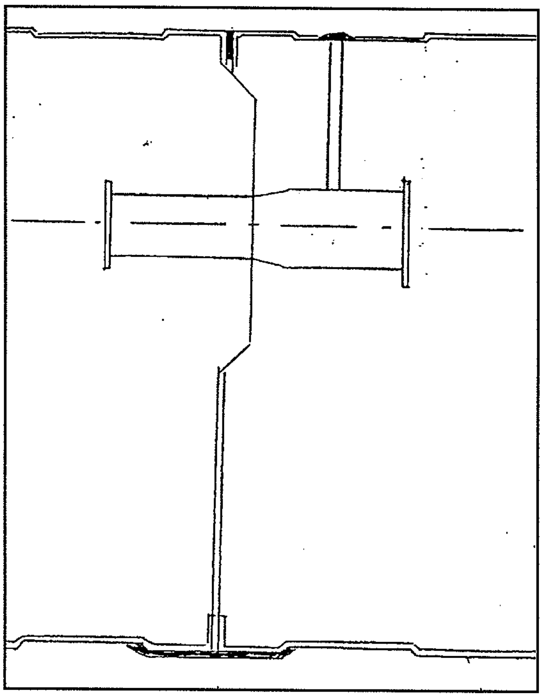


Figure 4 The assembly details for the sandwich elements. The two elements are fixed by a plastic bolt and the joints sealed by silicone mass and ID-tape.

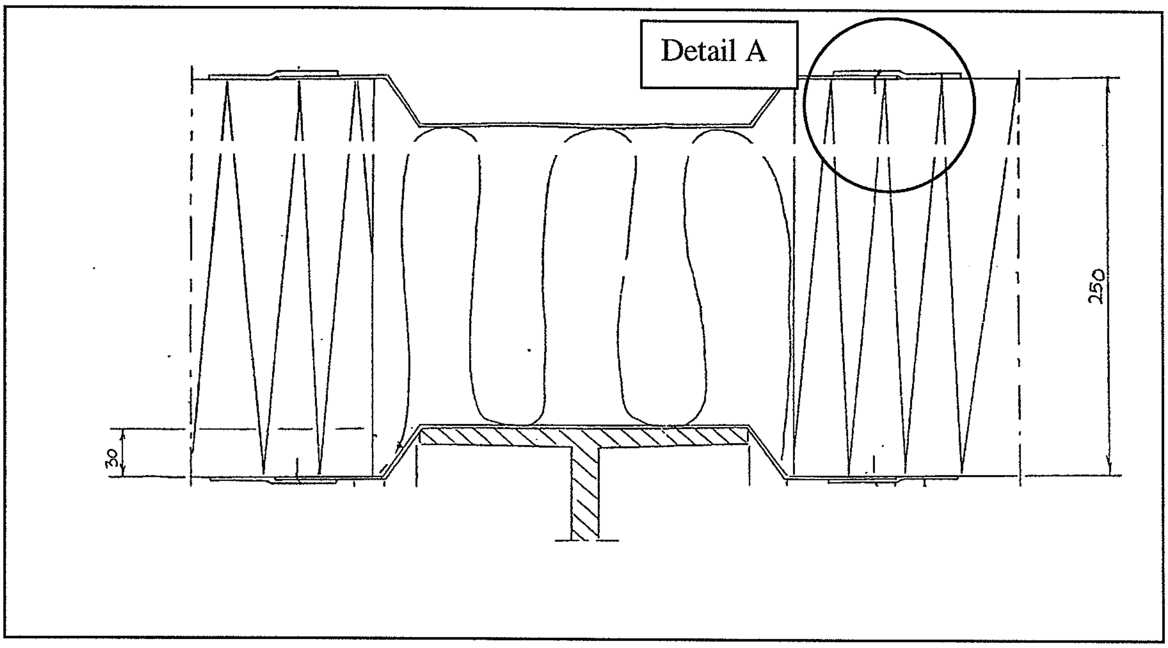


Figure 5 The assembly details for the sandwich elements. A special joint steel profile is fixed with pop-rivets onto the top- and bottom plate of the two sandwich elements. The joints are tightened by a two-step-sealing, shown in Figure 6. The gap between the elements is then filled with PUR-foam in situ. Note: The I-beam is in contact with the lid only if there is no water in the pit. Otherwise the lid is floating above the steel construction.

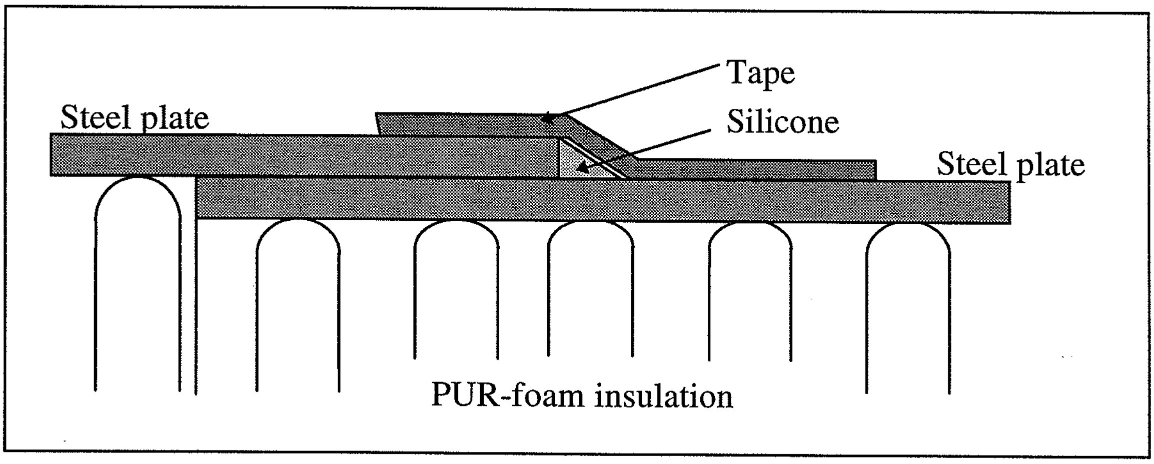


Figure 6 Detail A from Figure 5. The two-step-sealing; a primary sealing of silicone paste and a secondary sealing of a rubber tape which will be discussed in the following sections.

The edge elements are tightened by stainless steel profile jointed to the elements with pop-rivets and sealed by silicone mass and ID-tape. The border gap (ca. 5 cm) between pit-wall and lid is covered by a steel plate and an EPDM-liner.

To decrease heat losses due to evaporation, the gap between lid and pit wall is tightened by a steel profile.

In the case of an empty storage, the sandwich elements are held in position by a supporting steel construction as sketched in Figure 7.

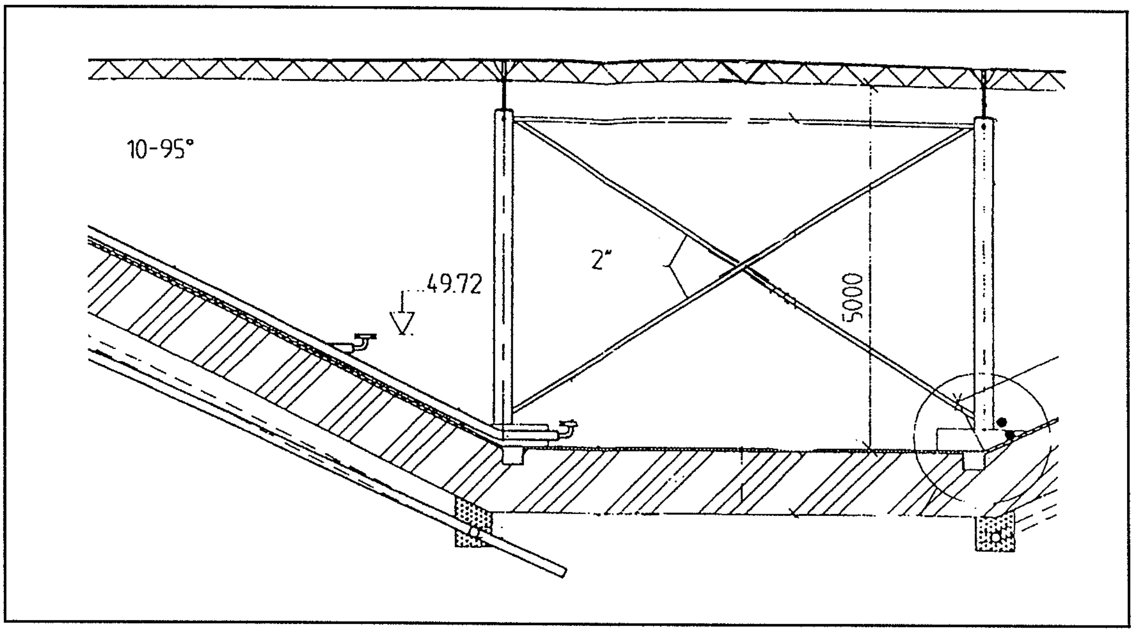


Figure 7 The steel construction supporting the floating lid for the case where no water is in the pit.

The procedure of gathering the lid in situ is discussed in Section 4. The overall construction of the pit water storage Ottrupgaard can be found in Appendix A.

3. Lid Testing

For investigating the suitability of floating lid designs, a simple test facility is built at the Department of Buildings and Energy. The facility is described in Section 3.1. Test lids are produced, including all the details that are applied to the Ottrupgaard lid and then examined in the mentioned test facility. The procedure ensured the capabilities of the manufacturers, showed production difficulties, difficulties with details and so on. Hence the lid design could be improved. A first lid design was tested by [Duer, 1995b]. Test results are summarized in Section 3.2. In Section 3.3 the redesigned test lid is described in detail and test results discussed. Due to the fact that the real Ottrupgaard lid is made as the second test lid, experience from the redesigned test lid can be transferred to the real lid and forecasts on the mode of operation can be made.

3.1 The Testing Facility

A test facility is designed for examining lid constructions under realistic conditions. The test lids are exposed to outdoor climatic conditions, floating on hot water. A square vessel with side lengths of 1.5 metres and a height of about 1 metre is built for testing purposes. The vessel is shown in Figure 8. The wooden bearing construction of the vessel is tightened by 0.8 mm zinc plates and insulated by 200 mm mineral wool. The vessel is heated by eight 200 W elements, placed between zinc plates and the insulation layer.

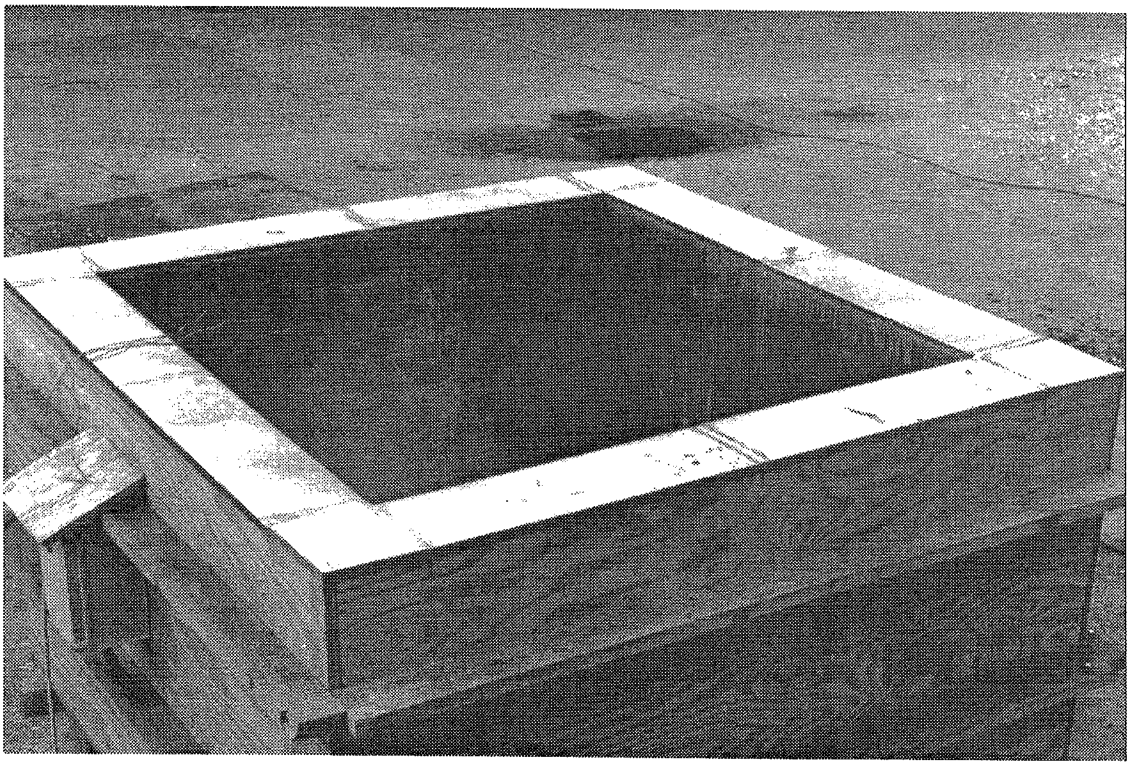


Figure 8 : Test vessel

Water is filled into the vessel to a level where the lid is floating in a desirable position. The water is coloured by a tracing chemical. Hence water penetration into lid construction can be detected. Before testing lid constructions the test facility is examined for e.g. tightness, sufficient and constant heating supply and for correct and stable thermostat control.

After initial difficulties with the heating elements and changing to larger effect, the facility was working stable with maximum temperatures swings due to hysteresis between 92 and 97 degrees Celsius.

To ensure proper examination, the test facility is prepared to deal with quadratic, floating lids up to 1.5 metres sidelength. The lids should include all problematic details as edges and assembly details etc.

Test lids and the Ottrupgaard lid are made and delivered by the Danish Company Hercules A/S. Sealing of the Ottrupgaard lid is unfortunately made by another team than the test lids which introduce a disagreement between the redesigned lid and the Ottrupgaard lid. Anyway this disagreement is minor compared to the observations made below.

3.2 Test Procedure and Results of First Test Lid Design

A picture of the first test lid design tested by Duer, 1993 can be seen in Figure 9.

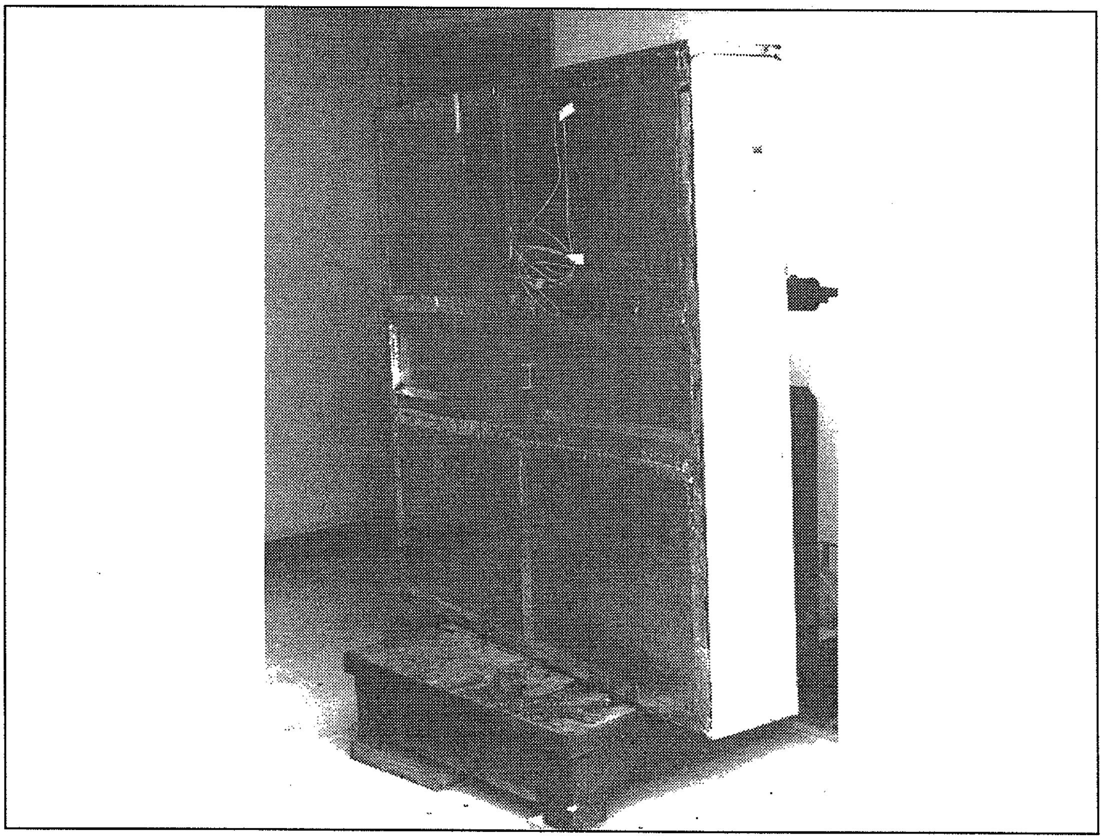


Figure 9 : The first test lid design.

The first test lid is floated over a period of 35 days with a constant water temperature of 95 degrees Celsius. The water and outdoor temperatures are monitored together with the weight of the lid. Before each weighing procedure the steelyard is calibrated by a control mass. Hereby the uncertainties are kept at an acceptable level. The lid is weighed after

18, 27 and 35 days. Hereby the water penetration into the construction is determined. Lid and control mass weights for the three measurements are shown in Figure 10.

Time, date	Results of weighing procedure [kg]		
	Test Lid	Difference per day	Control Mass
Start	72.6		72.6
18th day	74.5	0.11	72.6
27th day	75.8	0.14	72.6
35th day	76.3	0.06	72.6

Figure 10 Results from weighing procedure.

The uncertainty of the method is found to be less than 0.1 kg. Over the 35 days 3.7 kg water penetrated into the lid insulation. This penetration seems to decrease during the last period.

Note: Unfortunately, the weighing procedure was problematic to the lid which led to minor damage to the ID-tape. The lid had to be lifted by four men by lifting bars while balancing on the vessel construction. This had, without any doubt, affected the ID-tape. Anyway, this inexpedient handling and its damage on the tape has not had a relevant influence on the results.

After the 35 days the following observations were made by visual inspection of the lid:

- The assembly profiles applied to corners and edges were deformed, giving free passage to the hot water into the insulation layer.
- Assemblies, closed holes for foam injection and pop-rivet holes showed signs of corrosion.
- ID-tape at the corners are damaged, which can partly be explained by the rough handling of the lid at the weighing procedure.
- No signs of damage are found elsewhere on the ID-tape.

The lid is then examined by a destructive method. The following observations are made here:

- The edge profiles are gathered to the lid section by silicone only. This led to water penetration into the construction.
- Sandwich elements are assembled as shown in Figure 11 and sealed by silicone mass. This can led to leakage and water penetration into the insulation.
- Colour tracer is found in the lowest part along the assemblies.
- Water is found in all assemblies, but no colour is found apart from the mentioned.
- Water is determined between top plate and PUR-foam.

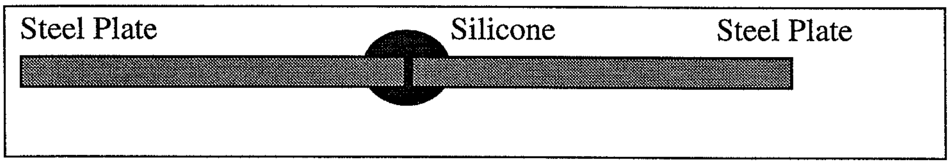


Figure 11 Assembly and sealing of two plates.

3.2.1 Conclusions from the First Test Lid Design

Joints and edges are not to be assembled by tape or silicone joint. The pressure due to heat expansion leads to breaks in the silicone sealing and thereby to leakage. It is advised not to use ID-tape at the edges, due to the mechanical exposure. Therefore, to ensure stiffness of the metal cover, corner and edge assemblies have to be welded, bend of one piece or to involve overlaps. Hence the sealing materials can be relieved from mechanical pressure.

Noticeable colouring of the PUR-foam proves water penetration through the bottom. As mentioned, water enters through the edges. But penetration through joints at the bottom is also possible. It is not clear if the hot water passed the double stage sealing by diffusion.

3.3 Test Procedure and Results of Redesigned Test Lid

Based on the experience from the first test lid a redesigned test lid was produced by Hercules A/S together with the Ottrupgaard lid in the same batch to ensure optimal similarity in e.g. material between test lid and full-scale lid. Unfortunately the man power and conditions under which the test was made were different to the man power and conditions for the Ottrupgaard lid. The test lid was joined under ideal conditions in a factory hall by well trained personnel. The Ottrupgaard lid was joined by personnel borrowed from a solar collector company and the sealing had to be executed from underneath the lid and partly under bad weather conditions. This personnel has done a really perfect job under the given conditions. Even so the quality is expected to be better for the test lid than for the Ottrupgaard lid. Hence observations from the test lid can be expected worse for the real lid in Ottrupgaard.

3.3.1 The Test Lid Design

Experience from the first test lid design led to the following changes of the lid design:

- Corners and edges are either made of one steel plate piece by bending or by full welding of the joints.
- Joints to be riveted are designed with overlap.
- A new ID-tape of rubber material only (General Electric Plastics, IDL 0314, delivered by DAFA A/S, Denmark) is applied for bottom sealing. At the top, the rubber, bitumen tape, used in the first design, is applied.

3.3.2 Tests and Investigations

The test procedure is basically similar to the procedures applied to the first lid. For the test of the redesigned lid, the water temperature is kept at 50 degrees Celsius, then raised to 70 degrees for another period. The weight of the lid is monitored and thermophotos are taken twice. To determine the effect of penetrating water into the lid construction, a number of measurement techniques are applied. Unfortunately, none of the techniques could describe the water diffusion and distribution in the lid, or the influence of the penetrated water on the insulation effect. At last, the lid is examined visually and demounted. A number of photographs are taken through the process for documentation. In the following the individual investigations are described and results discussed.

3.3.2.1 *Weighing*

During the test period the weight of the lid was monitored. The following increase in weight is found:

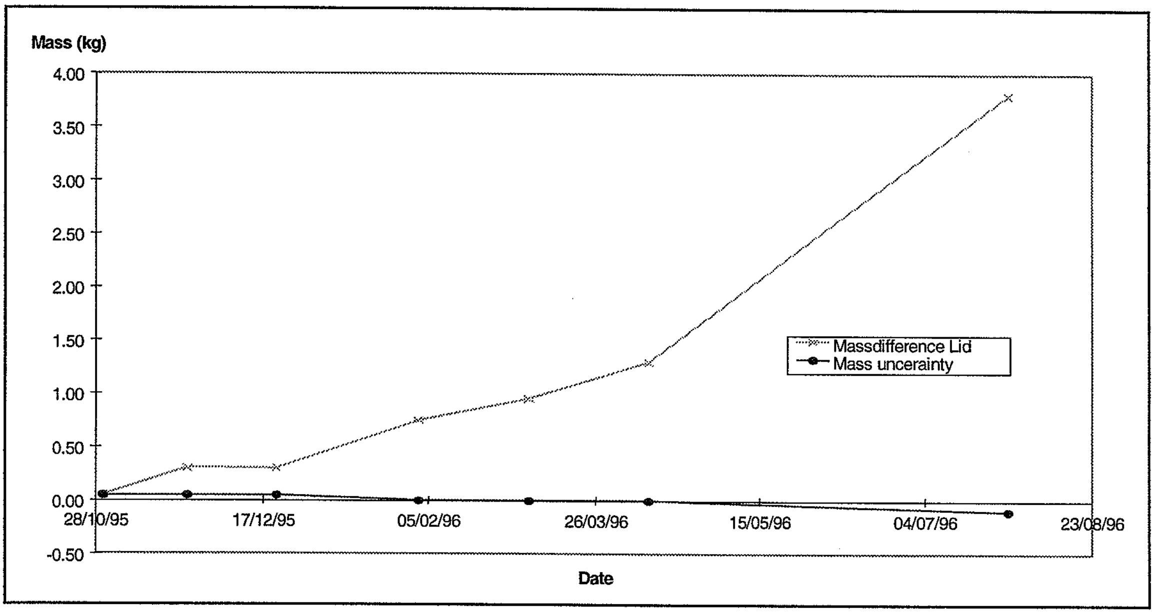


Figure 12 Increase of weight for the test lid due to water penetration and the uncertainty of the measurement.

Figure 12 shows that about 4 kg of water penetrate the lid construction during a 10 months' period. The uncertainty of the measuring method is about 0.1 kg.

3.3.2.2 *Thermophotos*

Two sets of thermophotos are taken by a Sonny Termovision system with a Nikkomat camera; one right after the floating of the lid and one three months later. The Termovision camera is cooled by liquid nitrogen. The technique of using thermograph is rather problematic. The weather conditions, the surface types and the angles from which pictures are taken influence the result. Due to the fact that the method gives relative temperature distribution over a picture area, the operator has to choose the temperature interval with care. Because of these facts the pictures are only used as guidance and not as precise evidences for one or another claim or conclusion.

From the thermophotos the following observations are made:

- Unfortunately the test lid was built by two different top cover materials; a grey and a white cover. The surface of the test lids therefore give different thermopictures.
- The temperature distribution across the lid is about 10 degrees by a water temperature of 70 degrees and an ambient temperature of a few degrees Celsius.
- The fully metallic borders and corners are heat bridges and lead to large heat losses.

- All joints lead to minor heat losses.
- Joints as shown in Figure 4 and Figure 5 lead to likely heat losses per area joint. Hence the two very different joint types are equally effective.

3.3.2.3 Measurements of Moisture and Heat Insulation

There were ambitions to measure the interdependence between occurrence of water in insulation material and the heat resistance. There were carried out measurements with a number of common known and less known measurement techniques. None of them could show the penetration of water into the construction or the influence of the penetrating water on the heat resistance. After the destructive examination of the lid some reasons for failure of the measurement methods were found. None of the methods could handle water lying directly under a metallic sheet. Anyway, the investigations were interesting and ought to be carried out under more controlled conditions.

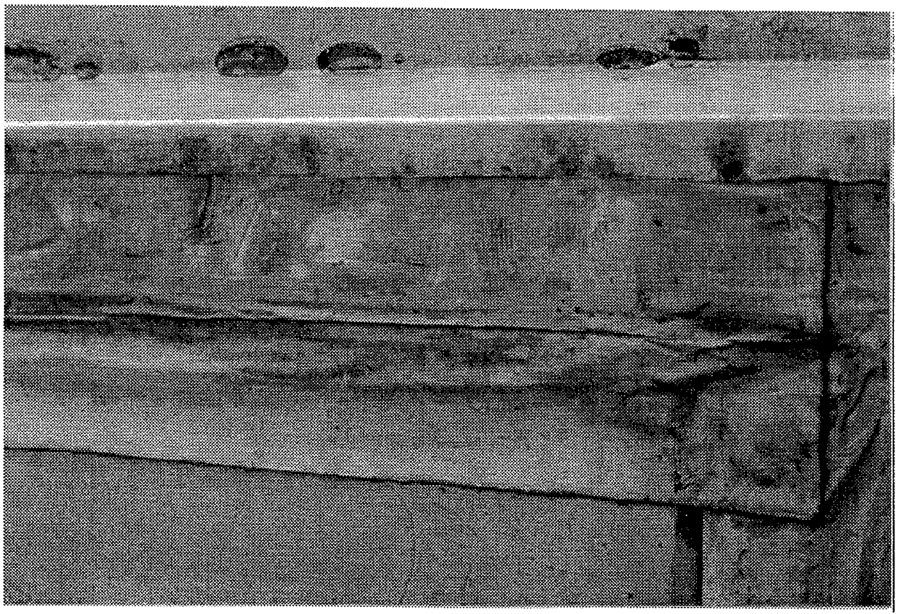
The following methods were or ought to be tested among others:

- Neutron measurements, Collet P. DTI-Building, Denmark.
- Capacity measurement with spear, Division Sensor Technology, FORCE Institute, Denmark.
- Acoustic methods, Collet P. DTI-Building, Denmark.

See also SBI-Anvisning 170, "Målemetoder til bygningsundersøgelser", the Danish Building Research Institute, 1990, for supplementary methods.

3.3.2.4 Visual Inspection

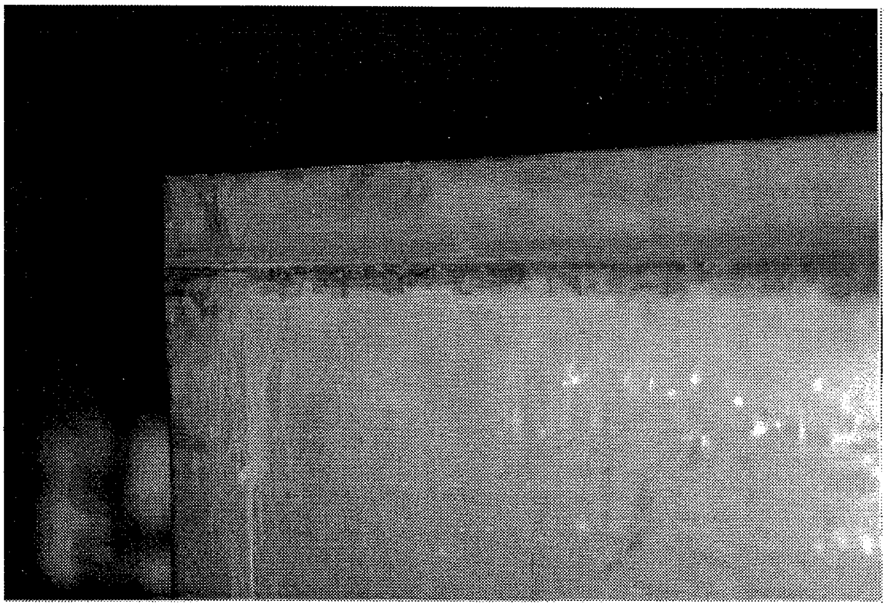
After the test period the lid is inspected visually. The following two pictures are taken hereby.



Picture 1 Picture of the visual inspection of an ID-tape detail. Dark parts are due to colouring from the tracer. Note the soft tape surface which shows that the aluminium film is loosened from the bitumen tape.

The following observations are made by the visual inspection of the test lid:

- The ID-tapes were affected by the temperature. The aluminium coating had loosened from the rubber. Anyway the rubber stuck perfectly to the steel sheets. Hence, the tape is expected to give the sealing a strength which the silicone mass could not be able to give. (See Picture 1)
- From the same photo one can observe that the lid was floating with an air bubble underneath the elements. The blue (dark) parts were in the water and therefore coloured by the blue ink. The rest was floating with no contact to the water. Hence corrosion problems due to the occurrence of chloride can arise at these spots. (See Picture 1)



Picture 2 Picture of the visual inspection of the stainless steel border. The dark parts are sediments from the water onto the steel sheets. No corrosion was found.

- At the waterline on the stainless steel boundaries, a brownish-yellow sediment can be seen. In the section about corrosion, 3.3.2.7, this sediment will be discussed further. (See Picture 2)

3.3.2.5 Destructive Examination

After the visual inspection the test lid is demounted and the following observations are made:

- The lid was extremely compact and stable. It was extremely difficult to take the construction apart.
- On the top and the bottom sealing the secondary tape sealing was passed by the storage water. Due to the fact that the tape sealing did not stick to the primary silicone sealing, there was free passage through the channels between the sealing. (See Figure 13)

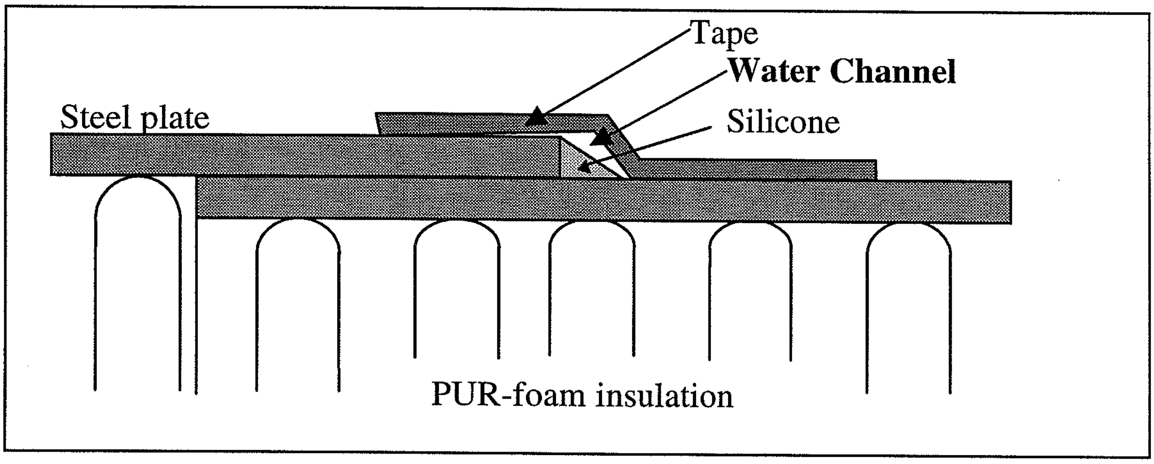


Figure 13 The two-step-sealing builds a water channel distributing entering water along all joints.

- On the top the primary and secondary sealing was passed by water. Corrosion was observed on all pop-rivets, holes, edges and joints.
- In the production, the sandwiches are filled with expanding foam. The foam makes a good contact to the steel sheets at the top and bottom, but in spite of this fact, small air spots occur where no contact is observed. Almost all of these spots were filled with water.
- It is not possible from the observations to explain where the water comes from and if the process will stop when all air spots are filled with water.
- On the other hand, one can conclude that the water has not affected the PUR-foam in a noticeable way.
- No water accumulation was found in the lower part of the insulation. No signs of corrosion was found in the lower part of the lid, also the secondary tape sealing was passed by the heated water. This will not be the case if the secondary sealing is imperfect.

3.3.2.6 Sample Water Penetration Tests

To examine the penetration of water into the PUR-insulation, two samples of the test lid material are floated in a water path; one sample at 50°C and the other at 70°C water temperature. The samples are weighed every few days to monitor the water penetration.

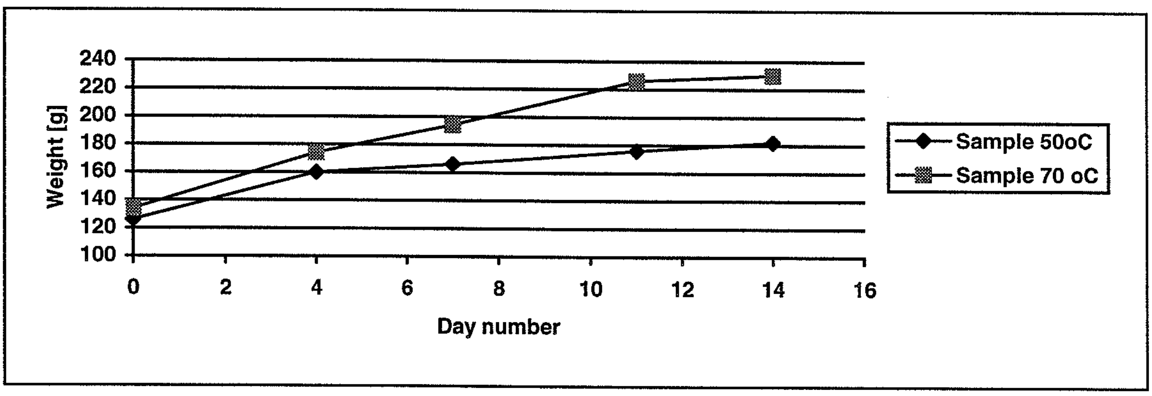


Figure 14 Hot water penetration into PUR-foam insulation through open surface.

It gets clear, seeing Figure 14, that

- the hot water enters the insulation foam
- the penetration depends on the temperature - higher temperature causes faster water penetration
- both curves show a decreasing slope in the last part of the examination. This seems to indicate a kind of growing resistance. The time period of the experiment is too short to make conclusions on this matter of growing resistance.

After the charge period the samples are cut into 8x8x1 cm slices. The slides are then examined by a weight-dry method. The following results are found:

Probe	P(wet)	P(dry)	dP	%$H_2$0
No.	23/01/97	30/01/97		
11	6.395	2.554	3.841	150
12	3.303	2.554	0.749	29
13	3.517	2.571	0.946	36
14	3.795	2.572	1.223	47
15	4.156	2.616	1.540	59
21	5.807	2.767	3.040	110
22	2.921	2.741	0.180	7
23	2.976	2.759	0.217	8
24	2.990	2.755	0.235	9
25	2.960	2.732	0.228	8

Figure 15 Results from drying-weighing method. The first column shows the probe number - 11-15 from probe one with water temperature of 50°C and 21-25 from probe 2 with 70°C. The P(wet) and P(dry)-columns show the weight of the probe for the wet and dry conditions. The difference in weight between wet and dry probe is shown in the dP-column which is the water that entered the probe. In the last column the water part relative to the dry weight is calculated in % of the dry probe.

The most important findings from

Figure 15 are:

- The first slice only for each probe is influenced by the water penetration.
- The two probes give quite different levels of water percentage for the "dry" probes. The first probe is at a level of 30-60% and the second of 6-8 %. No explanation can be made of this fact. An explanation could be that the procedure was not carried out properly which seems not to be the case due to the fact that the personnel is very experienced in its job. Another explanation could be that the probes, even taken from the same sample and close to each other, could involve different material components due to the fact that PUR-foam is rather inhomogeneous.

The conclusion of the experiment is clear - PUR-foam is entered by hot water. On the other hand, it is not clear if the penetration stops at a saturation point and if the penetration destroys the plastic cells and thereby destroys the insulation effect of the material. More detailed work is to be done on this and corresponding subjects and experience made in the EFP-research program of the Danish Energy Agency is to be gathered.

3.3.2.7 Corrosion

The lid is constructed of a rather cheep stainless steel of type X5 Cr Ni 18 10 (German standard). One expects corrosion problems due to the combination of high temperatures and the occurrence of non-treated tap water. Tap water includes chlorine which will turn into chloride on the waterline of the storage. Chloride corrodes even stainless steel types. At the Department of Manufacturing Engineering a sample of the metal border of the test lid was examined by Prof. Maahn to be able to predict the possibility of corrosion on the Ottrupgaard lid. The following conclusions were made by this expert:

- It is expected that temperatures above 50-60 °C will lead to a critical corrosion situation for the given stainless steel alloy.
- The two critical corrosion forms are stress corrosion and pitting. Both forms are promoted by the occurrence of chloride and the occurrence of high temperatures. The lid construction is exposed to both the chloride and high temperature.
- There could not be found any sign of corrosion on the sample which makes it difficult to estimate corrosion in exact figures.
- For long-term application one cannot recommend the applied stainless steel alloy due to the fact that the applied alloy is very sensitive to the described corrosion types.
- It is recommended, with the given criteria, to apply at least acidproof steel type W.nr.1.4401 (German standard) or SS 2343 (Swedish standard) or even highly alloyed steel type W.nr.1.4539 or SS 2562. All alternative steel types will be more expensive than the applied types.
- There was observed a brownish-yellow covering which must originate from the untreated storage water.

The original test results can be found at Appendix C (in Danish).

3.3.3 Conclusions from Redesigned Test Lid

The following conclusions can be made based on the examination of the redesigned test lid.

- The redesign of the first lid leads to more stable and tighter joints, edges and borders.
- The construction is still not water tight.
- The two-step sealing is not working properly. It is recommended to find an alternative technique.
- The bitumen-aluminium tape is not applicable to the given job.
- The silicone sealing seems to tighten relatively good.

- The application of pop-rivets leads to leakage. Therefore it is recommended to replace the technique by another method of joining metal sheets.
- The investigation could not unambiguously determine if the water found at the top of the lid construction was rain penetrated through the top lining or pit water diffused through the PUR-insulation. Anyway the investigation proves a transport of vapour through the insulation foam which could affect the insulation properties of the PUR-foam. This subject is discussed in Section 3.3.2.6.
- Although water enters the construction, this fact seems not to involve serious problems to the PUR-foam. Certainly the thermal insulation is decreased due to the penetrating water. The impact on the heat transfer could not be proved. It is recommended to work on this subject: How does penetrating water influence the interconnection between foam-materials and its heat insulation ability? How do heat and water influence the life length of the material?
- The applied steel type seems to meet the harsh conditions of the pit water. Anyway an acidproof or even highly alloyed steel is recommended for future designs.

4. The Ottrupgaard Lid - Investigations and Results

To examine the Ottrupgaard lid and its mode of operation, a number of investigations are performed. In this section the results are presented and discussed.

4.1 Levelling

The Ottrupgaard lid is designed with a slope of $3^{0}/_{00}$ to ensure a proper drain-off for rain water. The lid is levelled three times during the project period; after the pit was filled with water (15.09.1995), before the first summer (26.04.1996, cold water) and after the first summer (09.10.1996, hot water). Levelling notes are presented in Appendix B.

By levelling, a displacement of about 30-50 mm between two sandwich elements is observed right after the filling of the pit with water. Later levelling show that apparently the displacement does not influence the lid performance.

The measurements show among other things that the roof-shaped lid is disarranged. The lid hangs at the border elements which leads to pools of water collecting at the lid. After one season no damage on the lid is observed. The water pools seem neither to affect the level of the lid nor the performance of the lid. The stiffness of the lid elements and the top liner are crucial for the drain effect of the lid. A plastic liner, for example, would lead to problems.

4.2 Thermophotos

Thermophotos are taken by "Dansk LækageSporing, Termografi A/S". The first set of thermophotos are taken two months after the application and with cold (27 °C) water temperature, reported in [Janniche, 1995]. The second after the first year in action with hot water at a temperature of about 45 °C, reported in [Paulsen, 1996]. The Ottrupgaard lid is captured by 21 zone-pictures where the individual zones are marked by hot spots, candles. Although the pictures at Ottrupgaard are taken by specialists the problems with the method mentioned earlier are still valid.

From the first series exposed heat bridges are observed at point 17 and joints 9-12 and 20-24 where heat losses are considerably larger than for the rest of the lid.

From the second series exposed heat bridges are observed at the edges and the inspection lid. The heat bridges from the first investigation seem not to lead to considerably higher heat losses compared with other joints and edges.

At a water temperature of 45 degrees the surface temperature for the lid lies at 4 degrees and the heat bridges at between 5 and 11 degrees. A thermophoto of a typical lid section is shown in Figure 16.

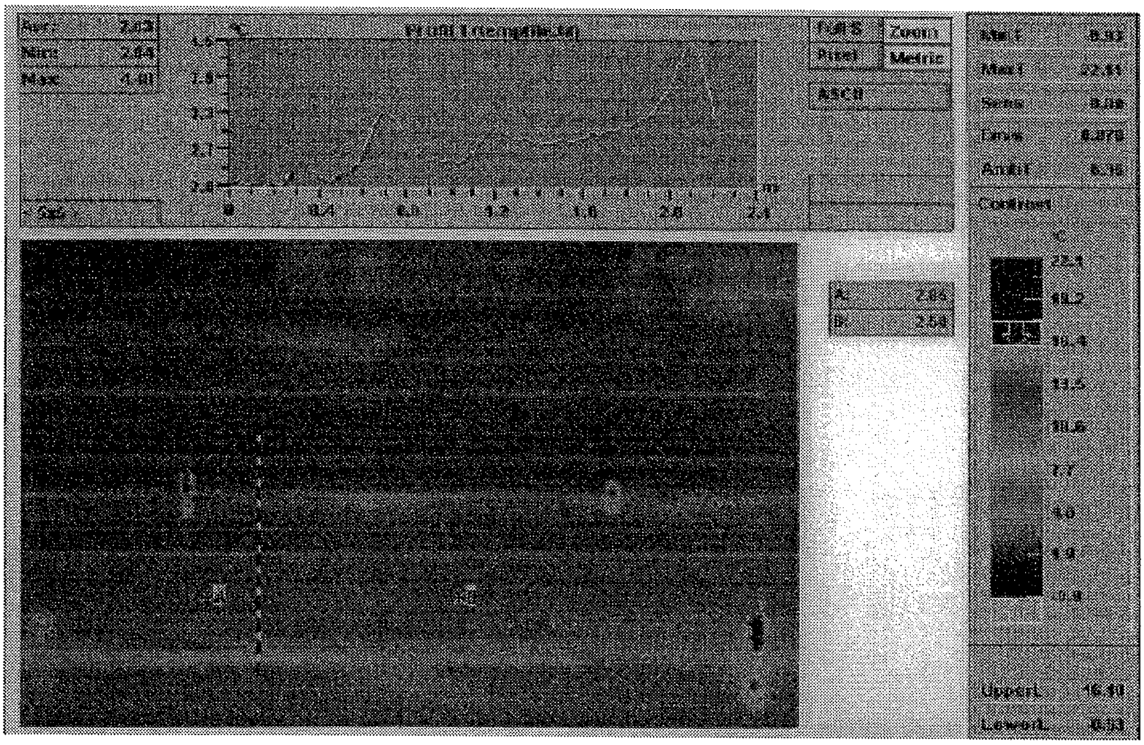


Figure 16 Thermophoto of a typical lid section. No critical heat bridges are visual. The spots are due to candles used for orientation.

A picture of a typical border detail is given in Figure 17.

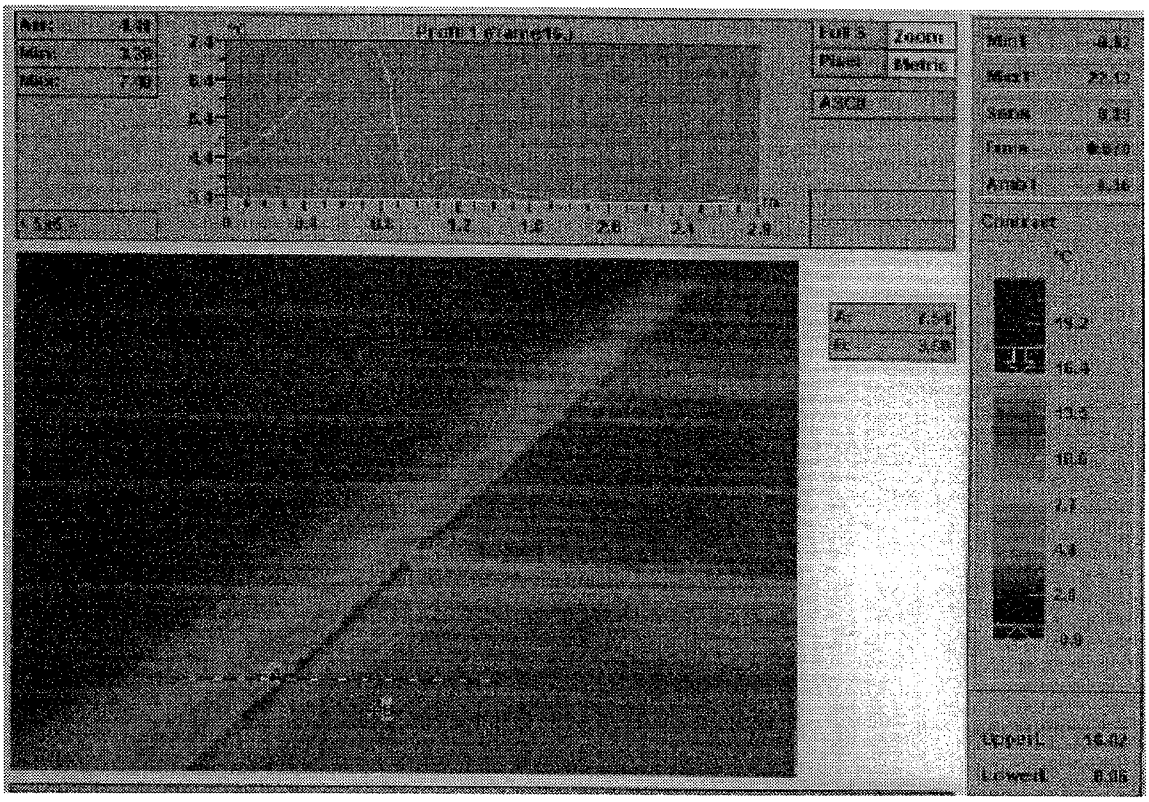


Figure 17 Thermophoto of a typical border detail. One can certainly see the structure of the lid and the border design.

The heat loss of the borders is much too high and need to be redesigned in the future.

At one corner the temperature raises to 12 degrees as shown in Figure 18.

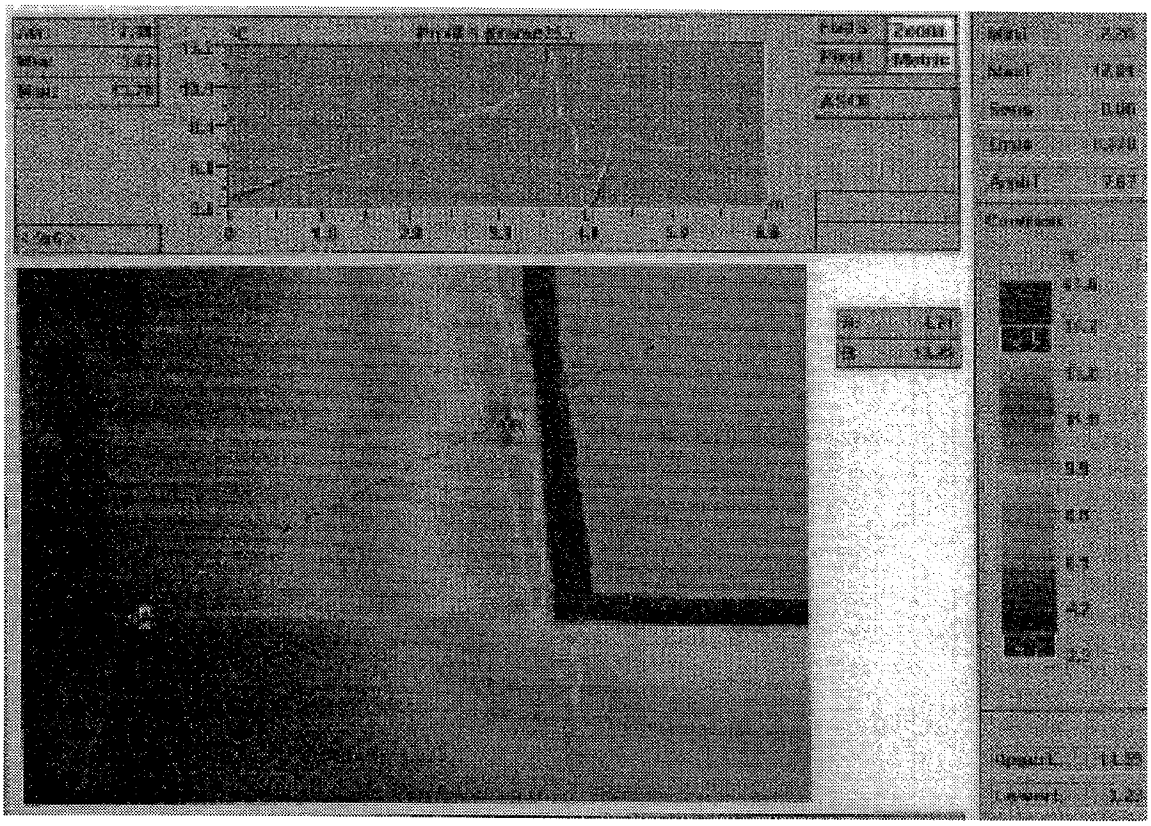


Figure 18 Thermophoto of a corner detail with specially high heat loss.

The heat losses can be traced up to 1.5 metres into the surrounding terrain resulting in a rather high heat loss through this detail. A photo of the same detail is given in Figure 19.

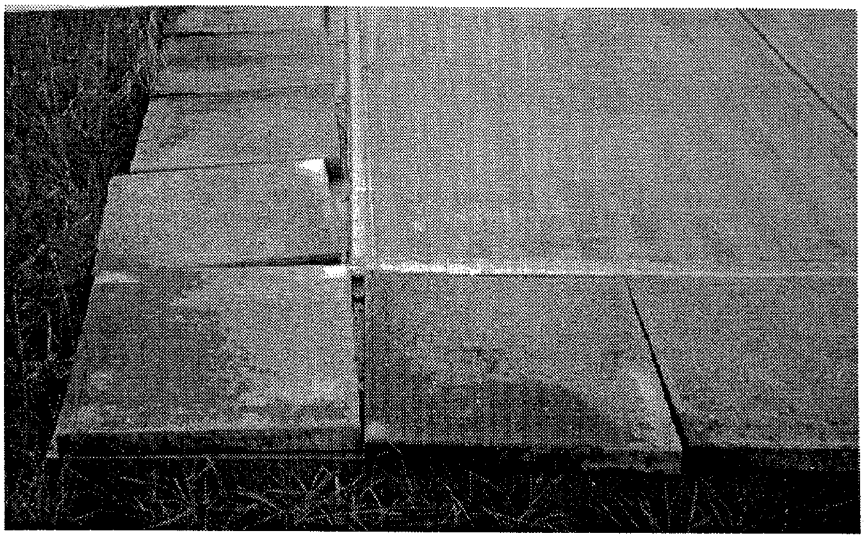


Figure 19 Photo of the same corner detail as above. The flagstones which should keep the construction tight are moved.

The overall heat loss for the lid is estimated to be around 3 kW. The edge and corner losses are about 1-2 kW which means a considerable heat loss. It is recommended to find a solution for the corner and edge losses.

4.3 Heat Loss Calculations

To examine the thermal performance of the Ottrupgaard Lid design, calculations with a 2-dimensional Finite Difference Program, HEAT2 [Blomberg, 1990] are executed.

The following model is applied:

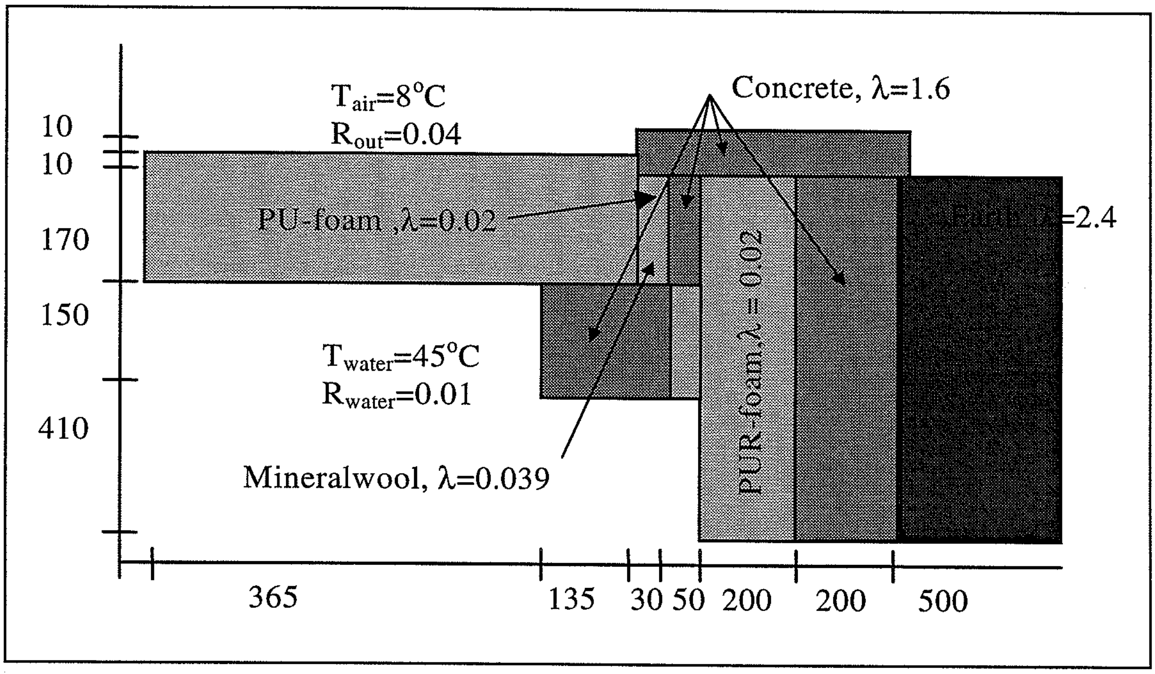


Figure 20 Lid border model for 2-dimensional heat conduction calculations.

For the two-dimensional finite difference calculations the boundary and material properties are shown in Figure 20. The convective heat transfer coefficient for the surroundings is the same as applied for building calculations and for the still water determined by measurements in water storage tanks.

The simulation showed the following ideal situation where no heat bridges occur:

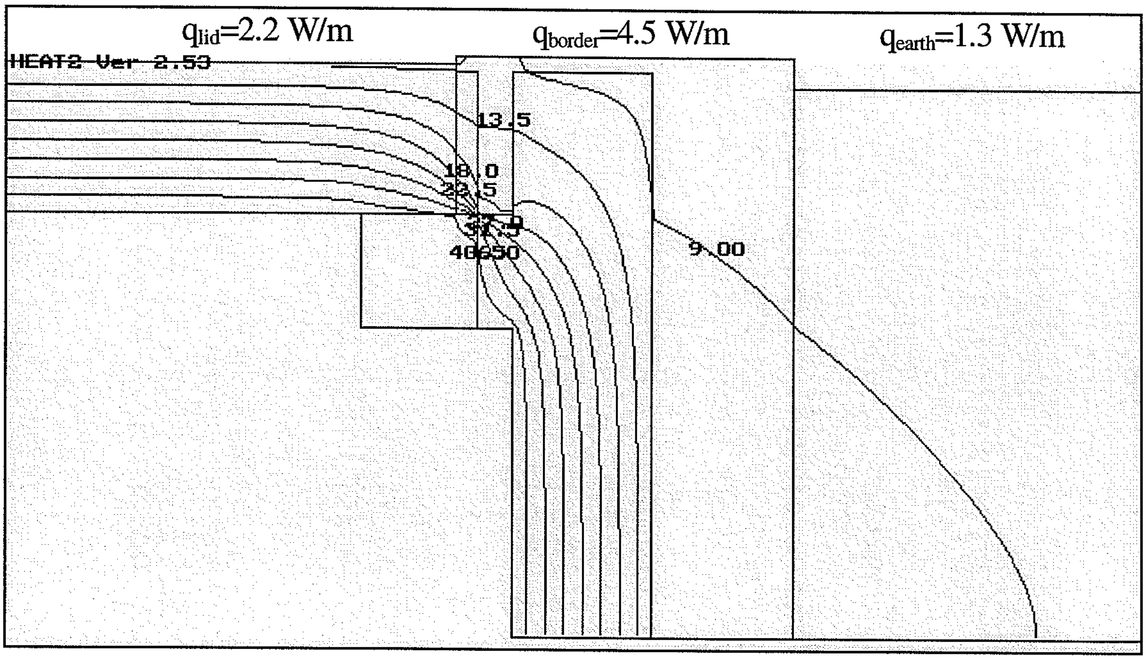


Figure 21 Isotherms and heat flow for an ideal construction of the Ottrupgaard lid design.

Figure 21 shows the isotherm for an ideal construction with no steel borders and no air space between lid and pit wall. This ideal construction lead to heat losses as shown on the figure.

Note: The heat losses are specified in W/m. To find the loss in W/m^2 one has to multiply by the length of the given detail, e.g. the length of the border around the pit.

Including the steel border the heat loss is estimated at

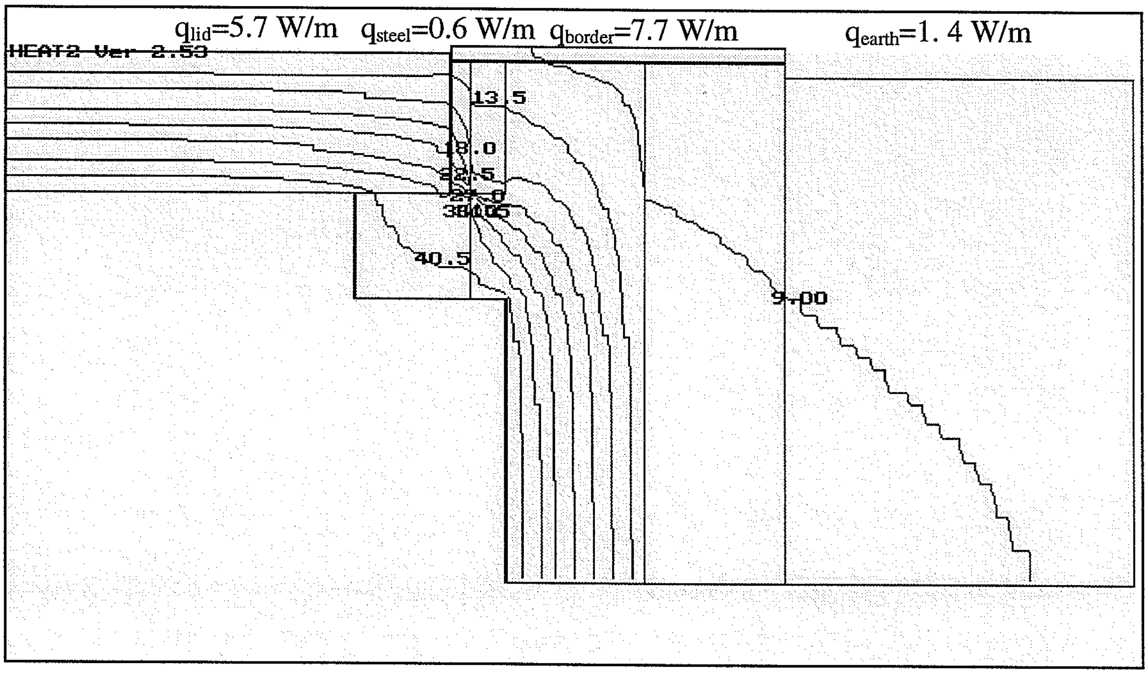


Figure 22 Isotherms and heat flow for the Ottrupgaard lid design including steel borders.

Figure 21 and Figure 22 show the following heat losses for the involved parts of the lid border construction.

[W/m]	Lid	Border	Earth	Steel	SUM
Simulation on ideal construction	2.2	4.5	1.3		8
Simulation on constr.with steel border	5.7	7.7	1.4	0.6	15.4
Difference	3.5	3.2	0.1	0.6	7.4

Figure 23 Estimates on heat losses by simulations through the lid part, the concrete, the soil and the steel border.

We se from Figure 23 that the heat loss through the steel border is minor (0.6 W/m and a very small area.] compared to the impact of this border on the rest of the construction. This is due to the lower temperature that arises along the steel border.

By a border length on about 110 metres the overall heat loss for the two simulations can be calculated at respectively 0.9 kW for the ideal construction and 1.7 kW for the overall heat loss with steel borders. The real heat loss will be even larger due to evaporation losses at the air gap between lid and pit wall which is not considered in the presented simulations.

The border loss can be estimated by applying ideal convectional heat coefficients as applied for the HEAT2-simulations and temperatures from thermophotos on calculations.

The air temperature is measured at $T_{air} = 8°C$.

The water temperature at about $T_{water} = 45°C$.

The average lid temperature $T_{lid} = 2°C$.

The average border temperature above the pit wall and the earth $T_{border} = 7°C$.

The width of the border heat bridge is chosen to be about 0.5 metres on both sides of the gap. With these temperatures and conditions the border heat loss for the same construction as above is estimated at

$$\begin{aligned} q &= q_{earth,border} + q_{border,lid} \\ &= \frac{1}{0.04}110 \cdot 0.25 \cdot (8-7) + \frac{1}{0.04}110 \cdot 0.5 \cdot (8-4) \\ &= 6.1\,kW \end{aligned}$$

The heat loss from corners is estimated in the same manner at about 0.5 kW. The overall heat loss on the borders is therefore estimated at 6.6 kW.

The lid itself leads to an overall heat loss of about $q = \frac{0.02}{0.25} 700 \cdot (45-2) = 2.4kW$.

Hence the heat losses due to imperfection of the borders account for at least $\frac{6.6}{6.6+2.4} = 0.73 = 73\%$ of the total heat loss of the lid construction even though the relevant border area makes up only 16% of the total lid area which is a serious heat loss. Experience from other lid designs shows border heat losses less than 25%. Rather simple improvements would solve this problem. Special attention must be paid to border constructions.

4.4 Physical Examination of the Lid

After floating the pit two divers inspected the lid and pit at Ottrupgaard. The first dive was executed at a water temperature of 30 degrees, the second at about 40 degrees. Scuba diving is not possible at higher temperatures. See Appendix B.

A position B3 is observed where two sandwich elements are displaced by about 30-50 mm. No damage is found at the sealing at the given area. The displacement is in the joint 20-24 where a heat bridge is observed. Due to the fact that the second thermograph has not shown any sign of higher heat losses at this position, the problem seems not to influence the overall heat loss of the lid construction.

At another spot the tape was found to be damaged. No other critical observations are made.

4.5 Conclusion from the Ottrupgaard Lid Examination

There are found a few defects at the bottom liner of the lid construction. One defect is found on the tape sealing. Another defect is a rather large dislocation of the lid at a joint. A reason for this dislocation could be an overpressure when foaming up a gap between two sandwich constructions. No damage was found on the tape sealing at the same joint. There was not found any serious heat losses at the dislocation. It is difficult to estimate the long-term effects of such a defect and its consequences.

Thermographical investigation and calculations have shown heat bridges at borders, edges and the inspection opening. The heat bridges lead to a considerable heat loss. Heat losses at the edges and corners can be diminished by insulating the gap between lid and pit wall. In the future borders are to be constructed with special care. Evaporation losses are to be eliminated.

Although levelling has shown problems that lead to water pits on the top of the construction, the stiffness of the lid leads to a satisfying rainwater draining on the top of the lid. Hence no negative consequences here from are detected.

5. Financial Aspects

The budget for the Ottrupgaard storage was in August 1993 estimated at 1.6 mill. Dkr. of which the lid was estimated at 600,000 Dkr. [Wesenberg, 1995b]. The real price ended at 1.8 mio Dkr. with a lid cost of 800,000 Dkr. ending up in a price of 1,200 Dkr. per cubic metre storage and 1,163 Dkr. per square metre lid.

As mentioned before, a lid is basically an insulation layer covered against ambient influences and the hot pit water. The insulation layer cannot be optimized above the choice of material and thickness and is therefore seen as a fixed expense. The cover at the top against rain water is a known technique and optimization is similarly limited. Hence the bottom lining and overall design are the two facts where the economy of the lid can be influenced. In the Ottrupgaard design one cannot make up exactly how much each part costs. Anyway an estimate is given in the following:

Lid part	Estimated Price Dkr.
Insulation material (0.2m*700 m^2* 500 Dkr/m^3) incl. foaming work	350
Top cover and assembly	100
Bottom lining and assembly	100
Border, corner, overall handling etc.	150

We see from the estimates that the fixed insulation material costs of a lid construction account for 50% of the total costs. Hence, 20% of the total cost can be seen as the variable part of the cost which can be economically optimized. Changing the overall design paradigm will certainly lead to other variable costs.

Hercules A/S has developed a new design which leads to prices for the panel of about 450-500 Dkr./m^2. The panels can be gathered very easily. The length of the element is free (unknown maximum length). The tightness of the joints has to be tested evt. improved.

In the report [Store Lager 4], a lid for a 100,000 m^3 water storage pit, 113x113 m, is estimated at 14.2 mio Dkr. or 1,130 Dkr/m^2 which is about 57% of the total cost of 33 mio Dkr. or 250 kr/m^3 storage volume. These prices will lead to heat prices for an end-user of about 504 Dkr./MWh exc. VAT which can compete with individual oil-heating but not with district heating based on biomass where the heat price lies at about 250 Dkr./MWh. exc. VAT.

On the other hand, if one compares different kinds of large storage types for seasonal storage, pit water storage is competitive with all known techniques. A steel tank of 100,000 m^3 will be built in two or three sections which will cost at least 45 mill. Dkr. with common designs. The price of the pit water storage is estimated at about 33 mill. Dkr. If the pit water concept is developed to a reliable level with the given price level, it can compete, at least in Denmark, with all known storage types.

We can therefore conclude that the solar heating pit water system cannot compete with district heating in the given form. Anyway, the pit water storage seems to be one of the cheapest seasonal storage types known at present.

6. Recommendations and Final Conclusions

There was found water penetration into the Ottrupgaard lid construction. The reason is untight assembly details which can be avoided by proper designing. Therefore it is recommended to work on the design to ensure a proper and tight construction. Assemblies should not appear under the water line. One should consider a design with small cells where no water can penetrate between. Thereby a leakage cannot lead to a total disaster.

As an alternative it is recommended to redefine the functions of the lid and the way to meet them. Doing so one finds that the current design tries to meet all functions in one boundary which seems not to be the most promising concept.

The overall lessons we can learn from the Ottrupgaard lid construction are:

- Any lid design has to be tested in a real small-scale experiment to avoid errors.
- The Ottrupgaard two-step sealing technique is not to be recommend due to the difficult handling and from an economical point of view.
- Any work on a lid construction must be done from the top of the lid. Work from underneath the lid is to be avoided.
- Borders and corners are to be designed with great care to avoid heat bridges and water penetration.
- Heat losses at Ottrupgaard are estimated at about 2.4 kW for the lid plus 6.6 kW for the borders and edges. The designer must optimize on this subject between economical and thermo-physical criterias.
- A highly alloyed stainless steel type is recommended for lid constructions.
- Stainless steel is an expensive material for lid constructions.
- Sandwich elements applied to lid construction is a good idea, if the joints can be assembled by cheaper and more reliable means.
- PUR-foam insulation seems not to be the most ecological solution for insulation.
- The overall price of the lid construction is about 57% of the total cost. Therefore an effort is to be made to lower the lid price and thereby to make the pit water storage an economical solution for seasonal storage.
- The lid design has to be improved to ensure reliability. Together with the economic aspect, this factor is the most important issue to be worked on in the future.

6.1 General Findings incl. Project Management - Method

The project has shown difficulties with the lid handling. In future lid testing, the lid handling has to be made much gentler. A lifting arrangement including the weight is to be developed and applied.

From the current project it gets very clear that a new design, not only of pit water lids, ought to be tested under real world conditions. The experience of the first test lid could prevent a rather catastrophic lid design. The testing of the redesigned test lid was too late for application on the Ottrupgaard lid which is seen as a mistake and is recommended to be done differently in other projects. Time managing is a key word for this problem. The financing parts are to be aware of this fact if the pilot projects are to succeed. All details ought to pass tests and should not be applied before passing such tests.

Thermophotos cannot be compared easily due to the relative representation of the object. The pictures are strongly dependent on the thermal circumstances at the moment at which the pictures are taken. Pictures taken under the same conditions can be compared. Pictures from different dates cannot.

All in all there is a need for further investigation on the effect of hot water on materials especially insulation materials' ability as insulators. There is a need of developing methods for the examination of insulation effect, the distribution of water in insulation materials etc. Due to the lack of these methods the current project was not able to answer many of the questions that arose during the project.

There are no methods for the measuring of conductive heat transfer and moisture in highly insulated constructions.

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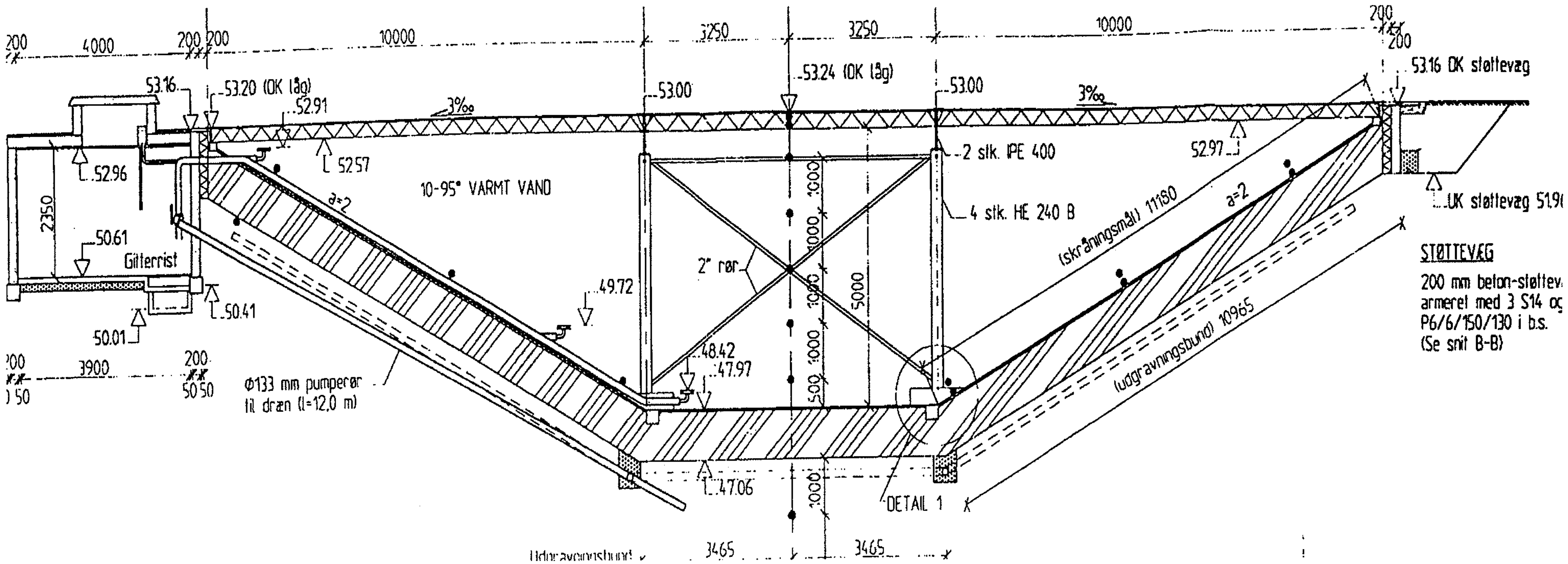
Note: It can seem confusing for outsiders that the following Institutes have old and new names:

	Danish	**English**
Old	Laboratoriet for Varmeisolering	Thermal Insulation Laboratory
New	Institut for Bygninger og Energi	Department of Buildings and Energy
Old	Danmarks Tekniske Højskole	Technical University of Denmark
New	Danmarks Tekniske Universitet	Technical University of Denmark

Appendix A: Drawings - Ottrupgaard Lid Design.



Appendix B: Note on Levelling of Ottrupgaard Lid.

Rapport

over opmåling og fotografering
af damvarmelager ved
Ottrupgård.

Udført den 13/04-96 kl. 17-18.

Formålet med den udførte opmåling/fotografering, var at kortlægge og præcisere eventuelle utætheder eller ujævnheder i belægningen af SF-sten på bunden, samt at opmåle det flydende isoleringslågs niveau over betonkanterne og (øst-vest) I-jernslængdestøtterne.

Opmåling: Målepunkterne er opdelt i A og B punkter. A for lågets niveau over betonkanten i bunden (se fig. 1), B for niveau over I-jern (se fig. 2). De enkelte målepunkters placering er angivet på fig 3.

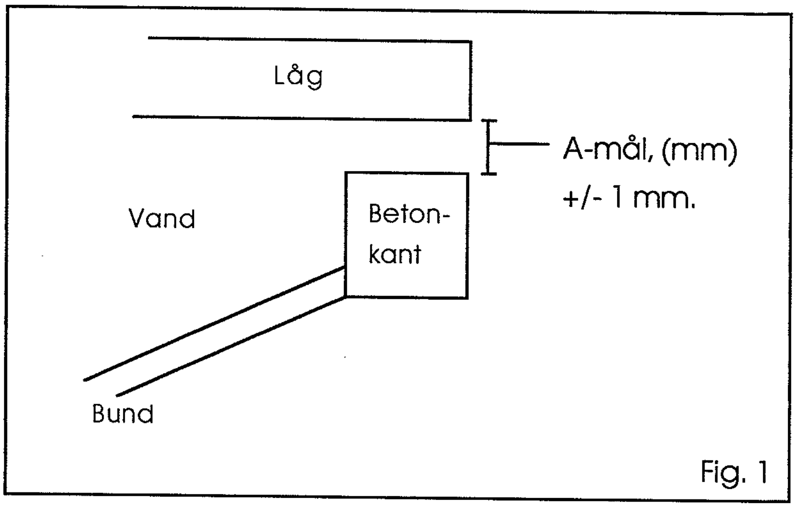


Fig. 1

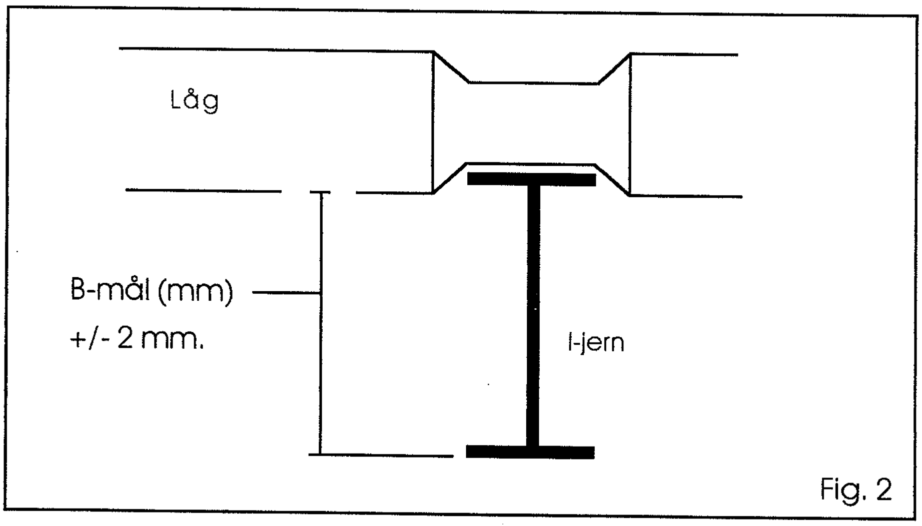


Fig. 2

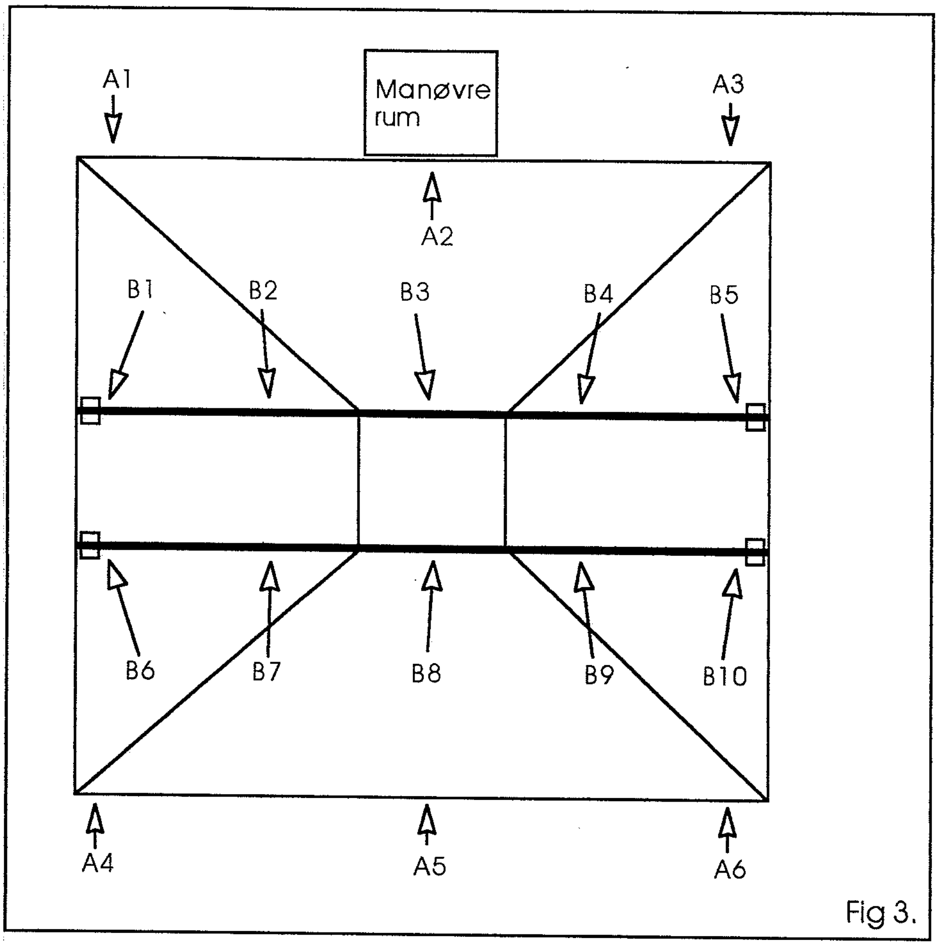


Fig 3.

Måleresultater:

A1	3 mm
A2	10 mm
A3	5 mm
A4	3 mm
A5	5 mm
A6	4 mm

B1	386 mm	B6	387 mm
B2	403 mm	B7	407 mm
B3	343 mm	B8	409 mm
B4	397 mm	B9	398 mm
B5	385 mm	B10	385 mm

Kommentarer: (Kun vedrørende opmåling og ID-bånd) Generelt var en nøjagtig opmåling af A-punkterne problematisk, på grund af den ujævne beton, og dette kan muligvis også være forklaring på A2.
Under kontrol af fugerne pådrog en enkelt samling vor opmærksomhed, omkring punkt B3. Her var en niveau forskydning mellem pladeprofilen i låget og et (eller flere) skumelementer (se fig. 4). Denne forskydning er af størrelseordenen 30-50 mm. (opmåling <u>ikke</u> foretaget). Vi bemærkede dog ikke nogle skader på ID-båndet ved forskydningen. Umiddelbart synede forskydningen ikke som en senere fejl, men derimod en konstruktionsfejl.
Der blev under kontrol af fuger også konstateret en skade på ID-båndet omkring punkt B2, ved to overlappende bånd. Skadens omfang var af ca. 4x15 cm, og der forefandtes ingen umiddelbare synlige limrester. Yderligere billeddokumentation følger i senere delrapport.
Generelt var båndene intakte og uden løsninger.

Det skal bemærkes at vi på øst- og vestsiden så flamingoelementer, som lignede en tiltænkt isolering af lågets kant. Vi kan ikke udfra de forhåndenværende tegninger udlede deres funktion, men kan fortælle at de ikke havde kontakt til låget, og at flere af elementerne lå skævt i forhold til lågets horisontallinie.

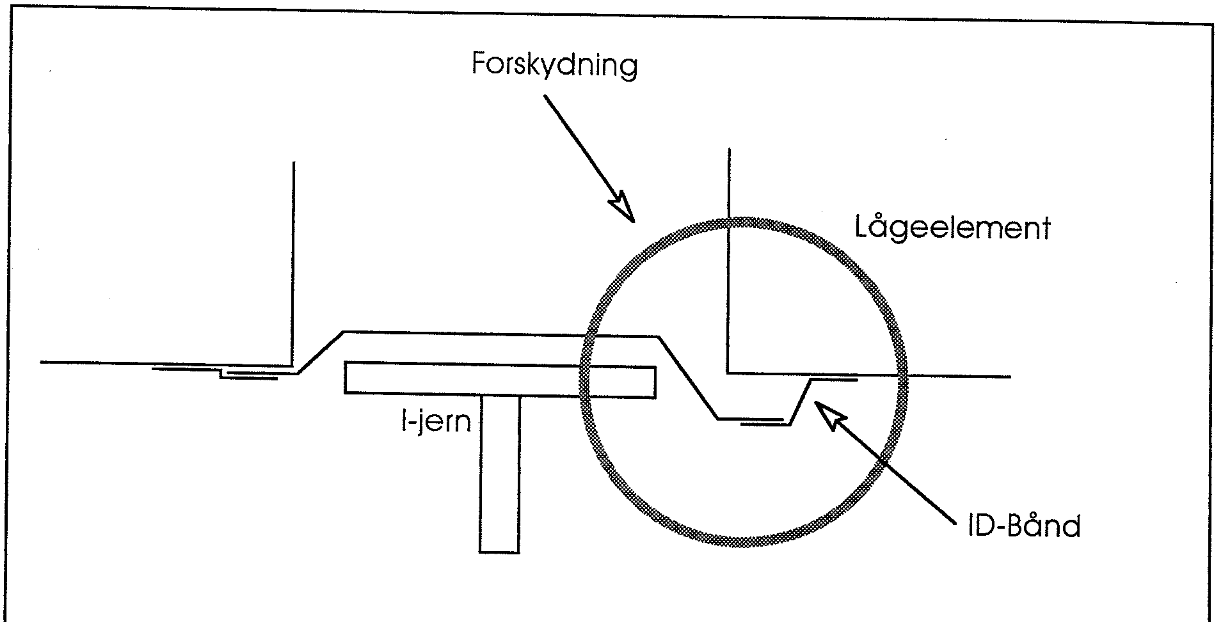


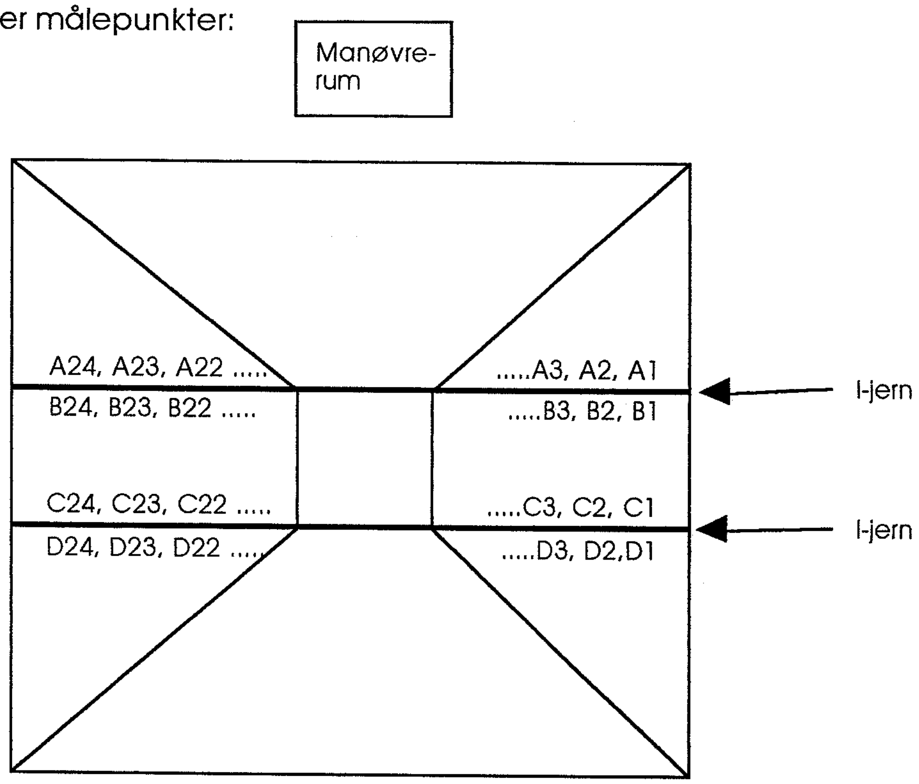
Fig. 4

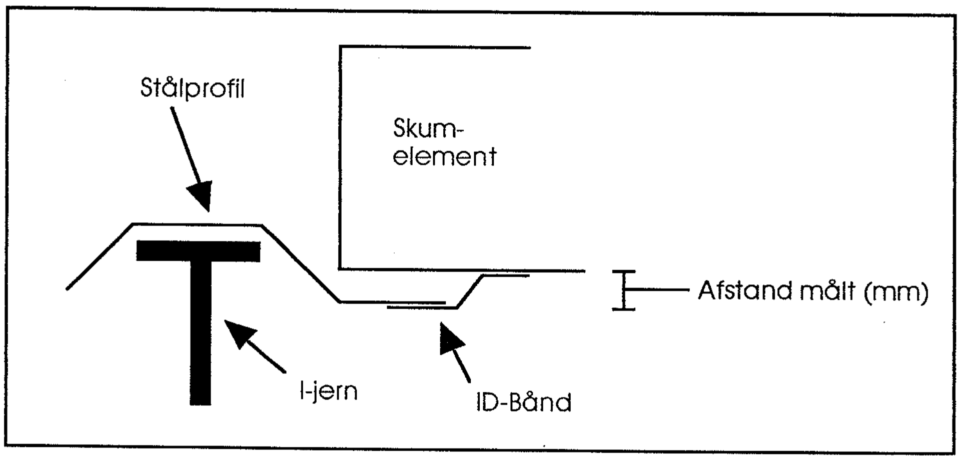
Delrapport over SF-stenbelægning og fotografering efterfølger.

Spørgsmål og kommentarer kan formidles gennem Ebbe Münster, Planenergi.

Opmålinger foretaget den 18/04-96.

Oversigt over målepunkter:





Måleresultater:

Pkt.	mm	Pkt.	mm
A1	10	A13	8
A2	10	A14	10
A3	10	A15	10
A4	10	A16	10
A5	10	A17	7
A6	10	A18	5
A7	10	A19	8
A8	8	A20	9
A9	8	A21	9
A10	8	A22	9
A11	8	A23	8
A12	9	A24	8

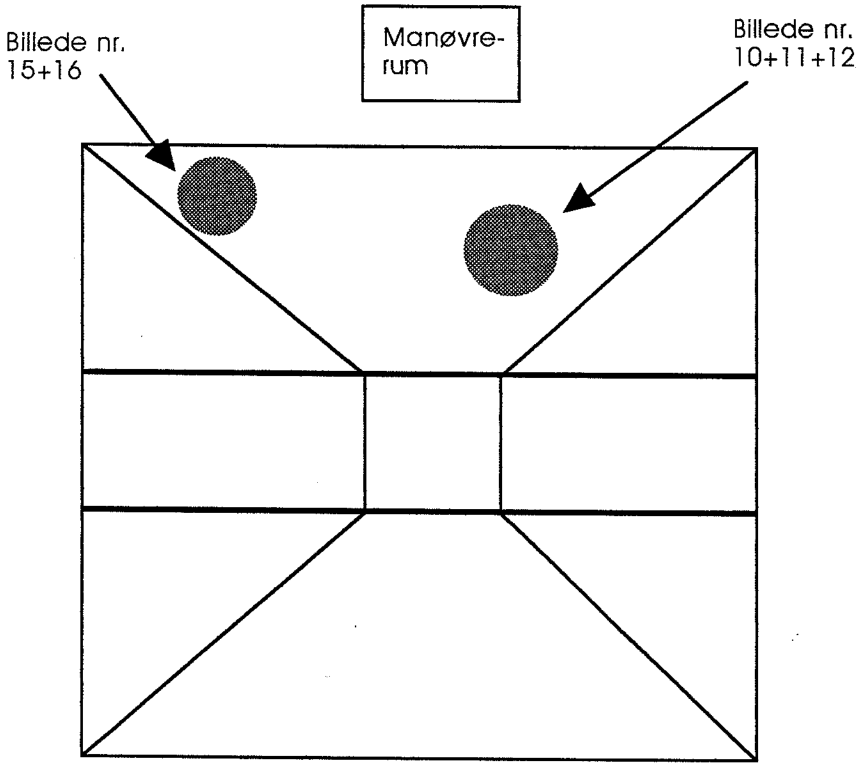
Pkt.	mm	Pkt.	mm
B1	6	B13	10
B2	7	B14	11
B3	10	B15	11
B4	7	B16	11
B5	8	B17	7
B6	8	B18	6
B7	6	B19	8
B8	5	B20	8
B9	8	B21	7
B10	8	B22	6
B11	9	B23	6
B12	10	B24	5

Pkt.	mm	Pkt.	mm
C1	9	C13	9
C2	9	C14	10
C3	9	C15	10
C4	9	C16	11
C5	9	C17	9
C6	10	C18	9
C7	9	C19	10
C8	11	C20	10
C9	11	C21	7
C10	11	C22	9
C11	10	C23	8
C12	10	C24	8

Pkt.	mm	Pkt.	mm
D1	7	D13	8
D2	7	D14	8
D3	10	D15	8
D4	8	D16	8
D5	7	D17	8
D6	6	D18	8
D7	6	D19	10
D8	10	D20	8
D9	9	D21	8
D10	9	D22	6
D11	9	D23	9
D12	9	D24	7

Fortegnelse over billeder af stenbelægning ved Ottrupgård.

Se billedenummer på bagsiden af billederne.



Nellemann, Nielsen & Rauschenberger A/S
RÅDGIVENDE INGENIØRER OG PLANLÆGGERE

Institut for Bygninger og Energi, DTU
Bygning 118
2800 Lyngby

25. oktober 1996

Att.: Alfred Heller

Projekt: Lågkonstruktioner til damvarmelagre

Hermed fremsendes som aftalt resultatet af nivellementerne på Ottrupgård-låget den
* 15.09.1995 (1)
* 26.04.1996 (2) og
* 09.10.1996 (3)

Endvidere vedlægges et par grafiske afbildninger af lågets projekterede tagform (A1, A2) og den indmålte lågoverflade 09.10.1996 (B1, B2).

Lågets funktion som tag (regnvandsafledning)
Lågets projekterede og indbyggede tagform fremgår af skemaet og figurerne A1 (grafer) og A2 (3-D bånd).

Lågets overflade ved nivellement den 09.10.1996 fremgår af skemaet og figurerne B1 (grafer) og B2 (3-D bånd).

Sammenholdes de projekterede og de indmålte overfladekoter, ses det, at lågelementerne "hænger" i yderfagene (modullinie A og E) i forhold til den indbyggede tagform.

De lunker, der opstår ved at lågelementerne "hænger", har i tidens løb givet anledning til regnvandsansamlinger i lange perioder.

Som det ses af tallene, har låget dog næsten ikke bevæget sig op/ned fra den 26.04.1996 (2) til den 09.10.1996 (3) - den gennemsnitlige bevægelse er jf. skemaet af 10.10.1996 kun ca. 1 mm.

NNR

Nellemann, Nielsen & Rauschenberger A/S
Rådgivende ingeniører og planlæggere
A/S Reg. nr. 48.398, tilsluttet F.R.I

Digtervejen 11
DK-9200 Aalborg SV

Telefon 9818 1344
Telefax 9818 3328
Telex 69 848 dencon dk

Der er således ingen tegn på en accelererende nedbøjning af låget under lunkerne, hvilket må betyde, at regnvandet i lunkerne ledes ud til lågkanterne på samme måde som regnvand på en flydende isflage ledes ud til siderne.

Der er dog ingen tvivl om, at lågets stivhed må være afgørende for, at låget ikke bøjer yderligere ned under lunkerne; En flydende gummi-liner vil utvivlsomt bevæge sig dybere og dybere ned i tanken, hver gang det regner.

Konklusion

Nivellement af den flydende lågkonstruktion på pilotprojekt 1.500 m3 damvarmelager i Ottrupgård i perioden fra september 1995 til oktober 1996 har vist

1. *at lågets indbyggede tagform ikke har virket efter hensigten og*

2. *at lågoverfladen på trods af regnvandansamlinger i lunker m.v. er stabil og kun bevæger sig få mm op og ned om året.*

Af opmålingerne kan således udledes: *at flydende lågkonstruktioner med en stivhed som den i Ottrupgård ikke nødvendigvis skal udføres med tagfald for bortledning af regnvand, hvis blot regnvandet kan ledes ud langs kanterne.*

Jeg håber du kan bruge ovenstående i din rapport og vender snarest muligt tilbage med den aftalte korte gennemgang af erfaringer med danske lågløsninger.

Jeg vedlægger til orientering kopi af nivellement af 18.09.1996, som viser overgangen fra fast til flydende tilstand umiddelbart efter fyldningen af tanken i september 1995.

Med venlig hilsen

Nellemann, Nielsen & Rauschenberger A/S

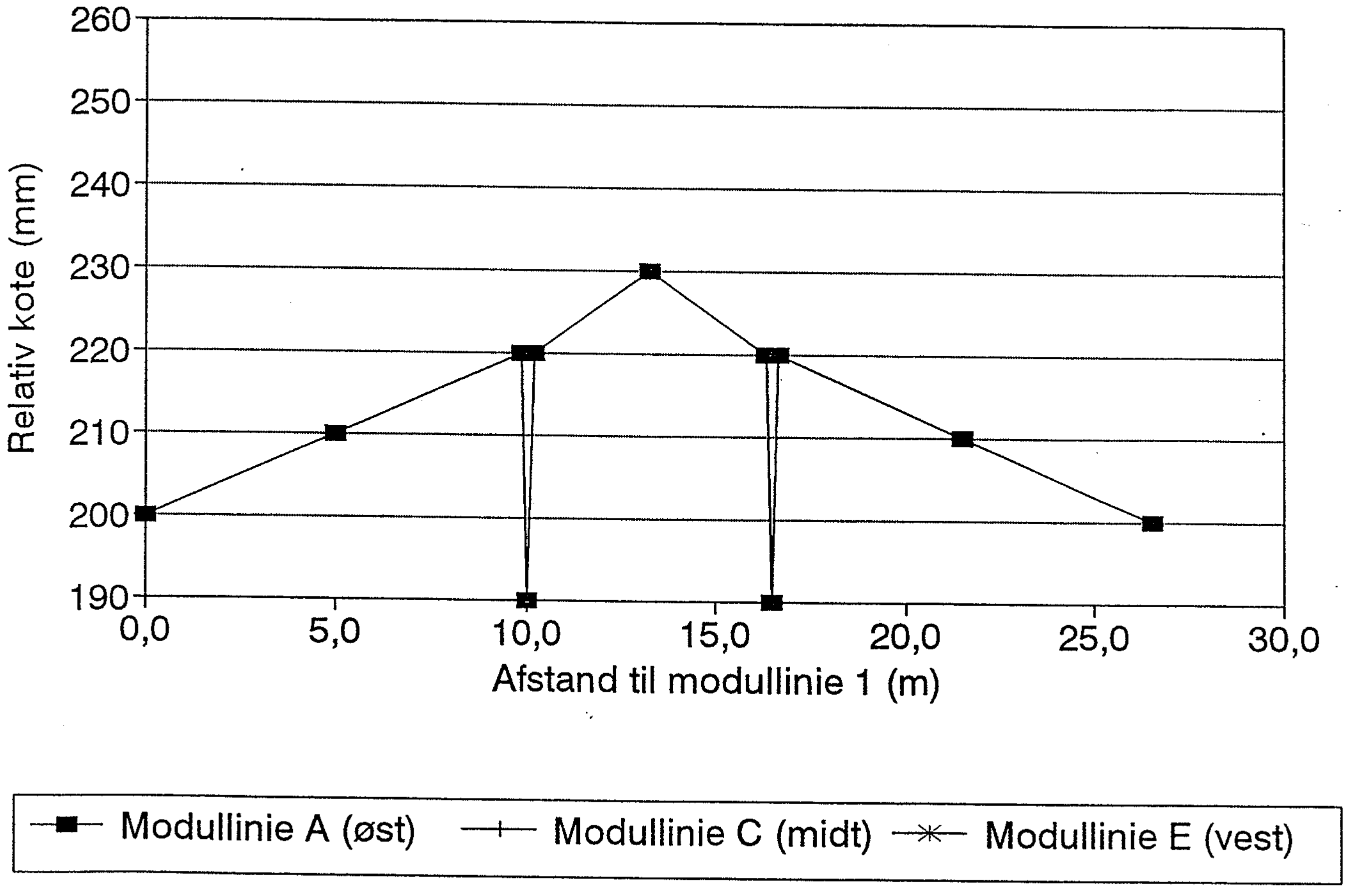
Carsten Wesenberg.

Carsten Wesenberg

A1

1.500 M3 PILOT-DAMVARMELAGER

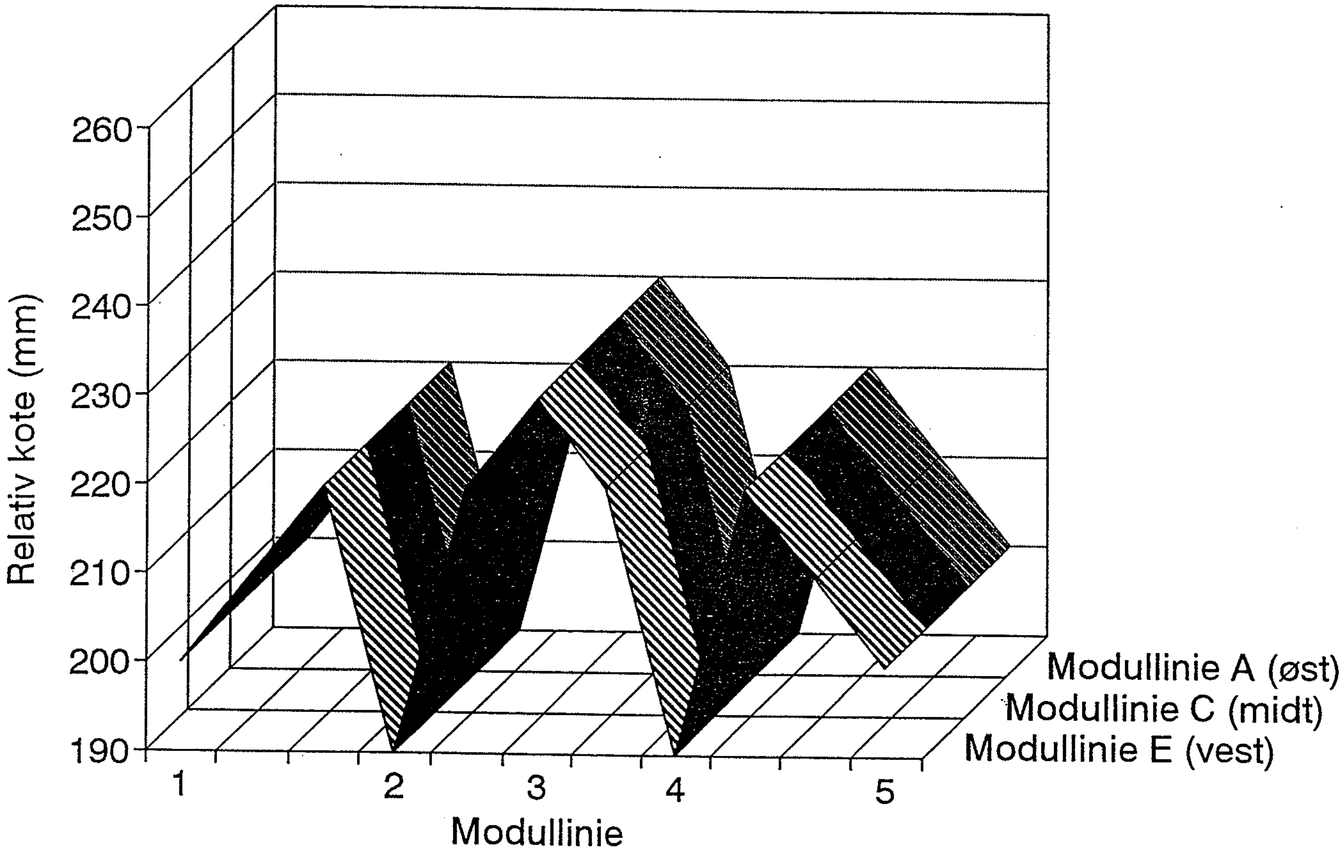
Lågets projekterede tagform



(A2)

1.500 M3 PILOT-DAMVARMELAGER

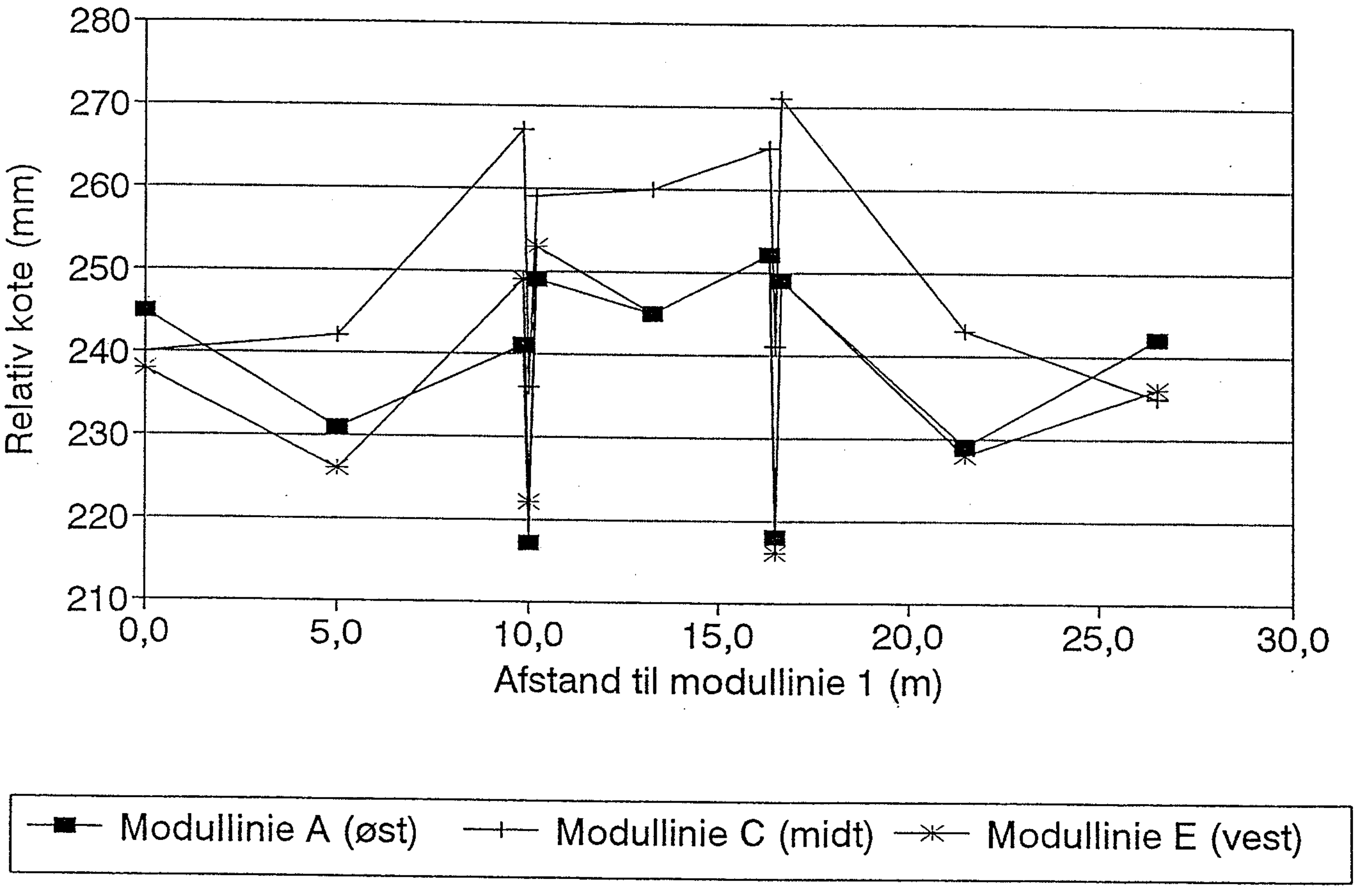
Lågets projekterede tagform



(B1)

1.500 M3 PILOT-DAMVARMELAGER

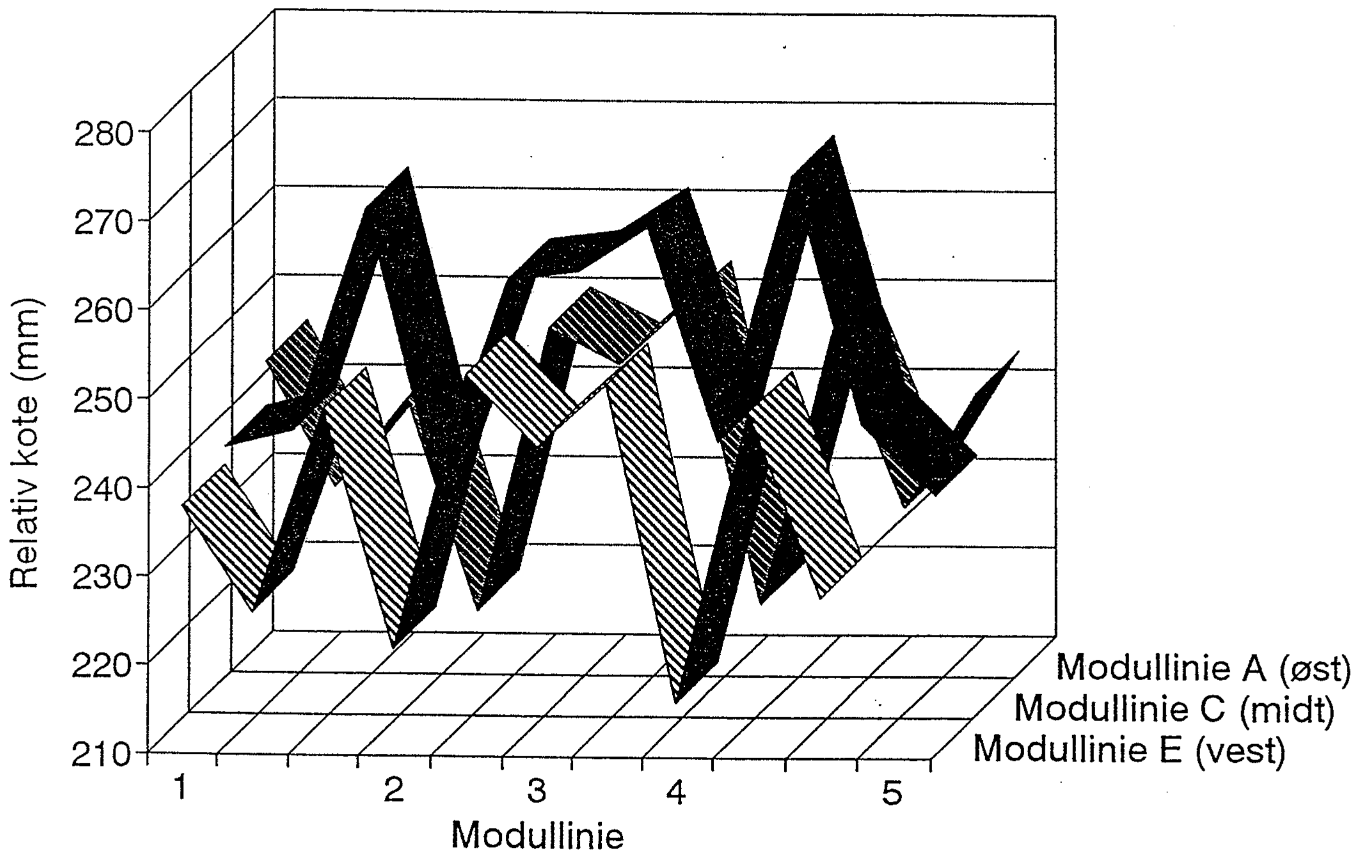
Opmåling af flydende låg 09.10.96



B2

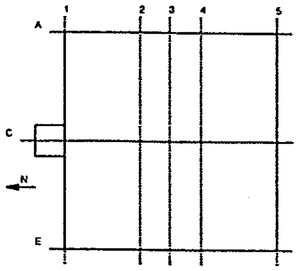
1.500 M3 PILOT-DAMVARMELAGER

Opmåling af flydende låg 09.10.96



OTTRUPGÅRD, 1.500 M3 DAMVARMELAGER

Opmåling af flydende lågkonstruktion



Alle koter er i mm.

Relative koter, OK betondæksel (over niveau-beholder) = 53709 mm NNR 14.06.1996

		Placering	Min. OK	OK låg, FLYDENDE			OK låg, FLYDENDE			
			Projekt	Nivellement 15.09.95 kl. 14:			Nivellement 26.04.1996			
			16.09.93	Sigteplan	803	mm	Sigteplan	719	mm	Bevæ-
MODUL			Kote	Aflæsning*	Kote	Afv.	Aflæsning	Kote	Afv.	gelse
A	1	1 NØ-hjørne	53200	1287	53225	25	1191	53237	37	12
		2 RS-kant	53210	1282	53230	20	1199	53229	19	-1
		3 RS-kant	53220	1268	53244	24	1176	53252	32	8
	2	Rendebund	53190	1302	53210	20	1213	53215	25	5
		4 RS-kant	53220	1271	53241	21	1180	53248	28	7
	3	5 RS-kant	53230	1266	53246	16	1185	53243	13	-3
		6 RS-kant	53220	1268	53244	24	1179	53249	29	5
	4	Rendebund	53190	1303	53209	19	1212	53216	26	7
		7 RS-kant	53220	1271	53241	21	1180	53248	28	7
		8 RS-kant	53210	1282	53230	20	1205	53223	13	-7
	5	9 SØ-hjørne	53200	1294	53218	18	1200	53228	28	10
C	1	1 N-midt	53200	1287	53225	25	1193	53235	35	10
		2	53210	1272	53240	30	1191	53237	27	-3
		3 RS-kant	53220	1262	53250	30	1155	53273	53	23
	2	Rendebund	53190	1295	53217	27	1197	53231	41	14
		4 RS-kant	53220	1267	53245	25	1175	53253	33	8
	3	5 CENTER	53230	1260	53252	22	1157	53271	41	19
		6 RS-kant	53220	1272	53240	20	1156	53272	52	32
	4	Rendebund	53190	1298	53214	24	1183	53245	55	31
		7 RS-kant	53220	1266	53246	26	1154	53274	54	28
		8	53210	1275	53237	27	1190	53238	28	1
	5	9 S-midt	53200	1289	53223	23	1197	53231	31	8
E	1	1 NV-hjørne	53200	1295	53217	17	1200	53228	28	11
		2 RS-kant	53210	1280	53232	22	1205	53223	13	-9
		3 RS-kant	53220	1271	53241	21	1181	53247	27	6
	2	Rendebund	53190	1296	53216	26	1208	53220	30	4
		4 RS-kant	53220	1265	53247	27	1177	53251	31	4
	3	5 V-midt	53230	1263	53249	19	1180	53248	18	-1
		6 RS-kant	53220	1265	53247	27	1177	53251	31	4
	4	Rendebund	53190	1300	53212	22	1202	53226	36	14
		7 RS-kant	53220	1267	53245	25	1181	53247	27	2
		8 RS-kant	53210	1276	53236	26	1203	53225	15	-11
	5	9 SV-hjørne	53200	1294	53218	18	1197	53231	31	13
				Gennemsnit, mm:		23	Gennemsnit, mm:		31	8
							Ekstra spædevand, m3:			5,5

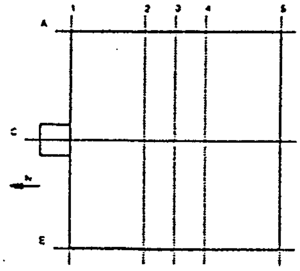
OK: overkant

UK: Underkant

*: Aflæsning i modul A1,A3,A5,C1,C5,E1,E3 og E5 v. ubelastet låg

SLUTRAPPORT 20/9-95

OTTRUPGÅRD, 1.500 M3 DAMVARMELAGER
Opmåling af flydende lågkonstruktion



Alle koter er i mm.
Relative koter, OK betondæksel (over niveau-beholder) = 53709 mm NNR 18.09.95

		Placering	Min. OK Projekt 16.09.93	OK låg, IKKE FLYDENDE Nivellement 01.09.95 Sigteplan 745 mm			OK låg, FLYDENDE Nivellement 15.09.95 kl. 14:45 Sigteplan 803 mm			
MODUL			Kote	Aflæsning	Kote	Afv.	Aflæsning*	Kote	Afv.	Bevægelse
A	1	1 NØ-hjørne	53200	1238	53216	16	1287	53225	25	9
		2 RS-kant	53210	1247	53207	-3	1282	53230	20	23
		3 RS-kant	53220	1219	53235	15	1268	53244	24	9
	2	Rendebund	53190	1252	53202	12	1302	53210	20	8
		4 RS-kant	53220	1219	53235	15	1271	53241	21	6
	3	5 RS-kant	53230	1223	53231	1	1266	53246	16	15
		6 RS-kant	53220	1218	53236	16	1268	53244	24	8
	4	Rendebund	53190	1254	53200	10	1303	53209	19	9
		7 RS-kant	53220	1222	53232	12	1271	53241	21	9
		8 RS-kant	53210	1249	53205	-5	1282	53230	20	25
	5	9 SØ-hjørne	53200	1245	53209	9	1294	53218	18	9
C	1	1 N-midt	53200	1237	53217	17	1287	53225	25	8
		2	53210	1252	53202	-8	1272	53240	30	38
		3 RS-kant	53220	1227	53227	7	1262	53250	30	23
	2	Rendebund	53190	1257	53197	7	1295	53217	27	20
		4 RS-kant	53220	1226	53228	8	1267	53245	25	17
	3	5 CENTER	53230	1225	53229	-1	1260	53252	22	23
		6 RS-kant	53220	1228	53226	6	1272	53240	20	14
	4	Rendebund	53190	1259	53195	5	1298	53214	24	19
		7 RS-kant	53220	1229	53225	5	1266	53246	26	21
		8	53210	1253	53201	-9	1275	53237	27	36
	5	9 S-midt	53200	1239	53215	15	1289	53223	23	8
E	1	1 NV-hjørne	53200	1240	53214	14	1295	53217	17	3
		2 RS-kant	53210	1247	53207	-3	1280	53232	22	25
		3 RS-kant	53220	1220	53234	14	1271	53241	21	7
	2	Rendebund	53190	1246	53208	18	1296	53216	26	8
		4 RS-kant	53220	1220	53234	14	1265	53247	27	13
	3	5 V-midt	53230	1220	53234	4	1263	53249	19	15
		6 RS-kant	53220	1216	53238	18	1265	53247	27	9
	4	Rendebund	53190	1252	53202	12	1300	53212	22	10
		7 RS-kant	53220	1220	53234	14	1267	53245	25	11
		8 RS-kant	53210	1240	53214	4	1276	53236	26	22
	5	9 SV-hjørne	53200	1240	53214	14	1294	53218	18	4
				Gennemsnit, mm:		8	Gennemsnit, mm:		23	15
							Ekstra spædevand, m3:			10,3

OK: overkant
UK: Underkant

*: Aflæsning i modul A1,A3,A5,C1,C5,E1,E3 og E5 v. ubelastet låg

Appendix C: Note on Corrosion Investigation of Test Lid.

Procesteknisk Institut

KORROSION OG OVERFLADETEKNOLOGI

Bygn.204, DTU
2800 Lyngby
Tlf.:4525 2211 Fax:4593 6213

18.11.96

Alfred Heller
Inst.f.Bygninger og Energi
Bygn.118
DTU

Vedr.: Metaldel fra varmelager.

Fter aftale har jeg undersøgt et stykke rustfrit stålplade udskåret fra et låg til et varmelager. Det er oplyst at pladematerialet er X5 Cr Ni 18 10 efter tysk standard.

Det er endvidere oplyst, at pladen udsættes for en vandlinie, og det er spurgt, om hvilken risiko, der måtte være ved anvendelse af den anførte materialekvalitet under disse betingelser. Endvidere ønskes anbefaling til materialevalg for fremtidige konstruktioner.

Ad.1

Der kan ikke iagttages nogen tegn på korrosionsangreb på det modtagne pladestykke. De rustfarvede brune belægninger må være udskillelser fra vandet, der har stået i kontakt med pladen.

Ad.2

Den beskrevne anvendelse af pladekonstruktionen med en åben vandoverflade under mere eller mindre indampende forhold og svingende temperaturer, måske op til 50 - 60°C, kan frembringe en meget kritisk korrosionssituation for de rustfri stållegeringer.

De to kritiske korrosionstyper er spændingskorrosion og pitting. Begge fremmes af forøget kloridindhold i vandet og forhøjet temperatur samtidig med rigelig luftadgang, som ved en vandoverflade.

Da der ikke er set begyndende skader på det undersøgte pladestykke er det vanskeligt at sætte absolutte tal på korrosionsrisikoen, men ud fra et ønske om langtidsstabilitet vil man normalt aldrig anbefale den her anvendte legering, som må betragtes som ganske følsom overfor de beskrevne forhold både med hensyn til pitting og spændingskorrosion.

Ad. 3

De foreliggende oplysninger er ikke tilstrækkelige til at give et entydigt råd om valg af materiale, men det må tilrådes, at der i det mindste foreskrives "syrefast stål" svarende til:

W.nr.1.4401 (tysk standard) eller SS 2343 (svensk standard).

Afhængig af vandkvalitet, rengøringsprocedurer, maksimal temperatur og konsekvensbetragtninger, vil man normalt overveje en mere korrosionsbestandig stållegering til den beskrevne anvendelse, og jeg vil mene, at det korrekte materiale til formålet er den højere legerede, men også meget mere korrosionsbestandige ståltype:

W.nr.1.4539 eller tilsvarende svenske SS 2562

som dog naturligvis også vil være dyrere i indkøb.

Jeg håber disse oplysninger kan være til hjælp ved det fortsatte arbejde med konstruktionen, og jeg er naturligvis parat til at diskutere yderligere aspekter i sagen, hvis det er nødvendigt.

Med venlig hilsen

Ernst Maahn
Professor